A COMPARATIVE STUDY OF THE PHYTOPLANKTON POPULATIONS OF POLLUTED ST. JOHN'S HARBOUR AND UNPOLLUTED AQUAFORTE HARBOUR, WITH EMPHASIS ON EUTROPHICATION

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by

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ABSTRACT

Hydrographic and phytoplanktonic data from four sampling depths (0, 5, 10 and 22 meters) were collected during the summer and fall of 1969 and the spring and summer of 1970 from St. John's Harbour and Aquaforte Harbour, located on the south-east coast of Newfoundland. Eighty-five species and four unidentified categories (u-cells, flagellates, naviculoids and gymnodinians) were identified from seven algal classes. These were primarily boreal forms. The seasonal distribution pattern of the phytoplankton differed in the two harbours.

It was concluded that St. John's Harbour, which receives untreated sewage from the city and suburbs, and servies a combined population of approximately 93,500, was the more eutrophicated. Evidence for the eutrophic state was especially notable in the central basin (station 1) of the harbour. Here the bottom waters were deficient in oxygen especially during the summer months. Secchi disc readings were generally lower at this station. The annual standing crop at this station was almost three times that at Aquaforte Harbour. Greater concentrations of nannoplankton were supported by the higher nutrient content. One euglenoid occurred in bloom concentrations throughout the summer months, and may possibly be considered an indicator of organically-polluted waters.

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TABLE OF CONTENTS

	PAGE
INTRODUCTION	1
Coastal and Estuarine Phytoplankton Surveys ..	3
Estuarine Eutrophication Phytoplankton Surveys	4
REVIEW OF SOME LITERATURE ON EUTROPHICATION	5
Dissolved Oxygen	7
Transparency	12
Standing Crop	16
Indicator Species	22
DESCRIPTION OF THE INVESTIGATED AREAS	28
St. John's Harbour	28
Aquaforte Harbour	33
MATERIALS AND METHODS	37
Field Work	37
Laboratory Analysis	38
RESULTS	43
Salinity	43
Temperature	48
Oxygen	52
Secchi Disc	60
Phytoplankton	62
a. Monthly Comparison of the Total Phytoplankton Biomasses	62
b. Distribution of the Dominant Algal Groups	76
c. Comparison of the Distribution of the Algal Groups	78
Chlorophyceae	78
Xanthophyceae	80

PAGE

Bacillariophyceae 81
Euglenophyceae 81
Dinophyceae 83
Cryptophyceae 83
d. Comparison of the Distribution of the Major Species 86
μ-cells 86
Navicula spp. "D" 88
Navicula spp. "B" 90
Chaeroceros spp. 91
Euglena sp "A" 91
Euglena sp "B" 93
Phacus sp. 93
Peridinium depressum 94
Ceratium longipes 96
Ceratium arcticum 98
Ceratium fusus 98
Ceratium lineatum 99
Glenodinium sp. 99
Gymnodinium spp. "B" 100
Gyrodinium spirale 100
Gymnodinium pygmaeum 102

DISCUSSION 104
Circulation 104
Salinity 106
Temperature 107
Oxygen Correlation with Phytoplankton Productivity 109
Volume as a Parameter of Biomass 111
Variation of Volumes within Species 113
a. Comparison within the literature 113
b. Comparison within the present study .. 118

PAGE

Seasonal Distribution of the Phytoplankton .. 121

Phytogeographical Distribution of the Phytoplankton 123

Phytoplankton Distribution According to Size .. 126

Eutrophication 135

a. Oxygen deficit in the bottom layers .. 135

b. Turbidity 138

c. Standing crop and eutrophication 140

d. Nannoplankton association with trophic levels 142

e. Distribution of some major species and trophic levels 144

f. Euglenophyceae as indicators of trophic levels 152

SUMMARY AND CONCLUSIONS 156

APPENDIXES

I. Total biomass ($\mu^3.10^6/dm^2$) for each month at the three stations. 160

II. Monthly biomass of the major species, expressed as a percentage of their respective algal groups. 161

BIBLIOGRAPHY 167

LIST OF TABLES

TABLE		PAGE
I.	Examples of trophic indicator phytoplankton species, as selected by various authors. ..	24
II.	Salinity data for St. John's Harbour and Aquaforte Harbour.	47
III.	Temperature data for St. John's Harbour and Aquaforte Harbour.	50
IV.	Oxygen data in ml/l and percentage saturation [determined from Richards and Corwin's (1956) nomogram] for St. John's Harbour and Aquaforte Harbour.	56
V.	Secchi disc depths and equivalent extinction coefficients in St. John's Harbour and Aquaforte Harbour.	60
VI.	List of species identified and their volumes.	63
VII.	Number of cells per liter at the four sampling depths and the volume or biomass ($\mu^3.10^6$) under a surface area of 1 dm^2 for some major species.	68
VIII.	Percentage biomass of the various algal groups within the total phytoplankton population.	77
IX.	Comparative data on cell volumes (μ^3) selected from the literature.	114

TABLE PAGE

X. Seasonal variation in the volume ($\mu^3.10^3$) of four species at St. John's Harbour and Aquaforte Harbour. 119

XI. Phytogeographical distribtuion of the species found in St. John's Harbour and Aquaforte Harbour. 123

XII. Results of some nanno- and net plankton studies in various environments. 129

XIII. Percentage of total biomass represented by three sizes of phytoplankton at each station. 130

XIV. Percentage of the phytoplankton biomass caught by a No. 25 plankton net. From Yentsch and Ryther (1959). 132

LIST OF FIGURES

FIGURE PAGE

1. Hypothetical curve of eutrophication in a lake. From Hasler (1947). 6

2. Typical dissolved oxygen curves in oligotrophic and eutrophic lakes during summer stagnation. From Sawyer (1966). 8

3. Map of St. John's Harbour showing depth (m) and location of sampling stations. 29

4. Map of Aquaforte Harbour showing depth (m) and location of the sampling station. 34

5. Seasonal variation in salinity at the four sampling depths at Station 1, St. John's Harbour. 44

6. Seasonal variation in salinity at the four sampling depths at Station 2 (the "Narrows"), St. John's Harbour. 45

7. Seasonal variation in salinity at the four sampling depths at Aquaforte Harbour. .. 46

8. Seasonal variation in temperature at five depths at the three sampling stations 49

9. Temperature profiles showing thermoclines in August, 1969 at Aquaforte Harbour and in July, 1970 at Station 1, St. John's Harbour. .. 53

10. Oxygen profiles at the three sampling stations in 1969. 54

FIGURE PAGE

11. Oxygen profiles at the three sampling stations in 1970. 55

12. Comparison of the total biomasses at the three sampling stations. 75

13. Comparison of: (A) Chlorophyceae and (B) Xanthophyceae, as percentages of the total biomass at the three stations. 79

14. Comparison of: (A) Bacillariophyceae and (B) Euglenophyceae, as percentages of the total biomass at the three stations. 82

15. Comparison of the Dinophyceae, as a percentage of the total biomass at the three stations. .. 84

16. Comparison of the biomasses of the Cryptophyceae at the three stations. 85

17. Comparison of the biomasses of the μ-cells at the three stations. 87

18. Comparison of the biomasses of Navicula spp. "D" at the three stations. 89

19. Comparison of the biomasses of Euglena sp. "A" at the three stations. 92

20. Comparison of the biomasses of Peridinium depressum at the three stations. 95

21. Comparison of the biomasses of Ceratium longipes at the three ations. 97

FIGURE PAGE

22. Comparison of the biomasses of Gymnodinium spp. "B" at the three stations. 101

23. Comparison of the biomasses of Gymnodinium pygmaeum at the three stations. 103

24. Percentage biomass of nannoplankton compared to the total phytoplankton in waters of different degrees of trophy (schematic representation). From Pavoni (1963). 143

INTRODUCTION

Variations in the nutrient content of water bodies have been recognized since the turn of the century. The earliest researches were in the field of limnology, where scientists were concerned with the gradual increase of nutrients, originating from land drainage and precipitation, as natural maturation progressed. In the estuarine environment it was originally assumed that, because of the extensive flushing action of tides and river currents, an unlimited supply of nutrients could be tolerated. In fact, estuaries have long been used as "cesspools" for domestic and industrial wastes. However, not until the last decade has the trophic state of estuaries been the object of intensive research, as the ecological threat posed by man's waste-disposal practices has become fully recognized.

The present study is concerned with a comparison of the standing crop biomasses and of the species differences of phytoplankton in polluted St. John's Harbour, receiving high concentrations of nutrients from domestic drainage, and in relatively unpolluted Aquaforte Harbour, receiving comparatively low concentrations of nutrients. By using these biomasses, along with dissolved oxygen determinations, an attempt is made to determine the extent of eutrophication in St. John's Harbour as compared to Aquaforte Harbour. The morphology and location of St. John's Harbour and of Aquaforte

Harbour are sufficiently different that the latter could not be truly considered a "control" area. Nevertheless, it was thought that comparisons of the two areas would be valuable, since no other readily accessible locations, that were more alike, had significantly different pollution loads.

To date, little work on the problem has been done in the north-west Atlantic. These locations in Newfoundland are the most northerly estuarine environments on the exposed coastline of North America to be studied from a trophic point of view.

Coastal and Estuarine Phytoplankton Surveys

Plankton surveys date back to the late nineteenth century. They were sometimes part of extensive oceanic cruises in the North Atlantic, and were primarily concerned with the taxonomic and geographic boundaries of the different species. Most other recordings of phytoplankton populations were studies of seasonal distribution patterns of standing crop.

Riley et al.(1949) observed that ninety percent of the plankton studies in the western North Atlantic were carried out in coastal waters from Nova Scotia to Chesapeake Bay. These included the surveys of the following regions: Georges Bank (Riley, 1941b), Gulf of Maine and Bay of Fundy (Bigelow, 1926; Gran and Braarud, 1935), Frenchman's Bay and Penobscot Bay, Maine (Burkholder, 1932), Woods Hole region (Fish, 1925; Lillick, 1937), lower Narragansett Bay, Rhode Island (Smayda, 1957), Block Island Sound (Riley, 1952), James River estuary, Virginia (Marshall, 1967) and Chesapeake Bay (Wolfe et al., 1926; Patten et al., 1963).

Farther north, and probably more relevant to the present study are the surveys of St. Margaret's Bay, Nova Scotia (Saifullah, 1969),Baie des Chaleurs, New Brunswick (Brunel, 1962), the Flemish Cap and the Grand Banks (Movchan, 1967; 1970), the coastal waters of Labrador (Iselin, 1930) and the Labrador Sea (Holmes, 1956).

Estuarine Eutrophication Phytoplankton Surveys

There have been very few long-term studies of estuaries in relation to environmental changes brought about by the increased nutrient load. This is especially true of North America; although a number of studies are available which correlate eutrophication with biological and chemical observations. These include surveys of the Duwamish estuary, Washington Welch, 1968), of the Hudson estuary, New York (Ketchum, 1969; Howells et al., 1970) of the Potomac estuary (Carpenter et al., 1969) and of the Bedford Basin, Nova Scotia (Platt et al., 1970).

Basu et al. (1970) reported their findings in a comparative study of a polluted and an unpolluted estuary in the Bay of Bengal. In England, the effect of increased nutrients in the River Tyne was examined by James and Head (1970). One of the many reports on the River Thames was Rice's (1938) study of the phytoplankton at various stations along that river. A survey of the Noordzeekanaal showed the gradation of oxygen and phytoplankton populations from the North Sea to Amsterdam (Wibaut and Moens, 1957). The classic and extensive study of the Oslo Fjord (Braarud, 1945, 1953; Braarud and Bursa, 1939; Braarud and Ruud, 1937; Anon., 1968) provides a comparison with the main area studied in the present thesis, St. John's Harbour.

REVIEW OF SOME LITERATURE ON EUTROPHICATION

The term eutrophication had its beginings as early as 1907 when Weber described the high nutrient content of soil solutions of German peat bogs (Hutchinson, 1969). The term was introduced into limnology by Naumann in 1919 when he discussed eutrophic, oligotrophic and heterotrophic populations of phytoplankton. In 1931, he defined eutrophication as "an increase of the nutritional standards especially with respect to nitrogen and phosphorus" (Stewart and Rohlich, 1967). When this process occurs naturally, it is simply maturation. When it is induced artifically, as by the influx of human sewage, industrial wastes, agricultural drainage, forest mismanagement and urban runoff, it may be considered to be the result of pollution. However artificial eutrophication can also be beneficial, as in fertilized fish ponds.

Most early work in eutrophication was carried out in limnology, in which the basic concepts were developed. Nevertheless, such concepts are usually applicable to the estuarine and the marine environments.

Hasler (1947) interpreted the course of eutrophication in a lake, graphically (Figure 1). He believed it to be a comparatively rapid process following the sigmoid growth curve which was heightened extensively by the addition of fertilizers. The steep rise can be explained by the existence of reducing conditions in the bottom of a eutrophic lake, releasing additional

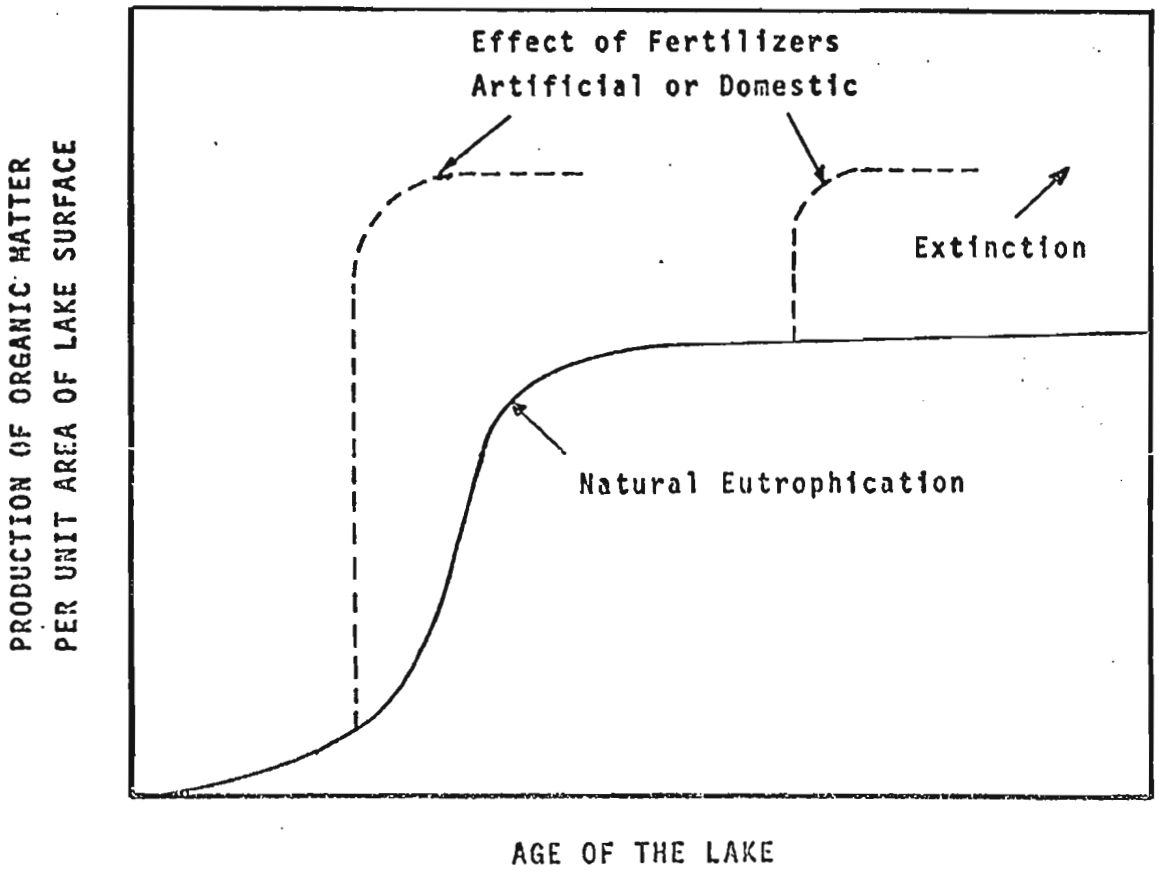

Figure 1. Hypothetical curve of eutrophication in a lake. From Hasler (1947).

nutrients for recirculation in the enclosed system.

Research into the dynamics of eutrophication established the parameters used in measuring this process. These parameters may be placed into two broad classifications: physical-chemical and biological. The physical-chemical parameters are usually direct measurements of the respective components in an aquatic environment e.g., dissolved oxygen, transparency, dissolved solids and nutrients, but they can only be considered as indirect ways of evaluating eutrophication because they are only relative to biological productivity. The biological parameters represent a more direct method of evaluating eutrophication since they usually measure biological productivity directly, e.g., chlorophyll, oxygen production and standing crop. A quantitative measurement of certain indicator species is also important under the latter heading.

The remainder of this section reviews the pertinent literature on the four parameters used in the present study.

Dissolved Oxygen

Oxygen determinations were one of the first parameters of eutrophication to be measured. Sawyer (1966) illustrated (Figure 2) a typical limnoligical situation. Dissolved oxygen analysis of lakes of varying production shows distinct differences during the summer stagnation period. The least

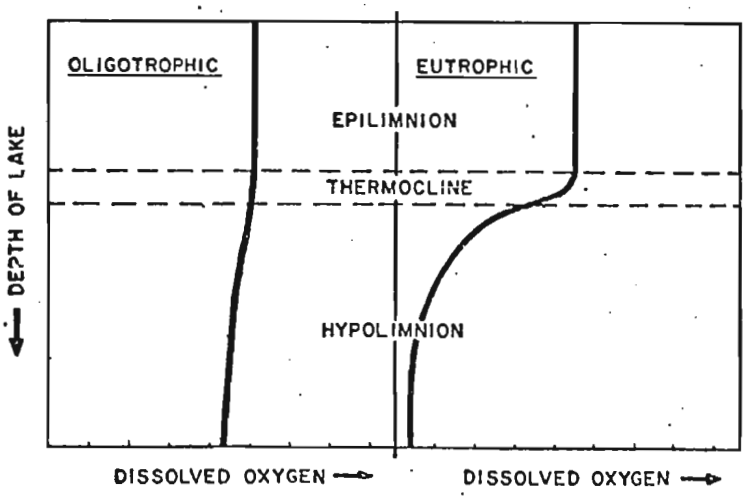

Figure 2. Typical dissolved oxygen curves in oligotrophic and eutrophic lakes during summer stagnation. From Sawyer (1966).

productive or oligotrophic lakes show little change in oxygen with depth, while the most productive or eutrophic lakes show a marked decrease in oxygen in the hypolimnion. In the latter case, the great quantity of organic matter produced in the epilimnion sinks below the euphotic zone where bacteria consume available oxygen. Sometimes accompanying the hypolimnion deficit is a supersaturated surface layer, where large quantities of nutrients premit high phytoplankton productivity to take place.

The deficit of oxygen in the hypolimnion has been frequently recorded, and definite trends toward an increase

in this deficit have been noted. For example, in the eutrophic lake, Esrom Sø, Denmark, having a depth of 22m, Jónasson and Mathieson (1959) recorded no oxygen at 18m, although supersaturated levels were recorded at the surface. Stewart and Rohlich (1967) cited the findings of Minder (1943) concerning Lake Zürich, Switzerland. By 1930, the lake showed a gradual increase of oxygen saturation in the surface waters and a decrease of oxygen at great depths. However, from 1930-1942 a rise was noted in the deep water indicating an improvement in water quality. Minder stressed that the oxygen content of a lake was the most important variable. In the Soviet Union, Straškraba and Straškrabová (1969), reporting from the literature, noted the depletion of oxygen at the bottom of the Caspian Sea around the mouth of the Volga. This occurred as a result of organic matter flowing from the river. Lund et al. (1963) showed that Lake Windermere in England had a steady decline of oxygen in the hypolimnion throughout the period of stagnation. In Alberta, Hastings Lake was designated as eutrophic by Bozniak and Kennedy (1968); the bottom waters of this lake were completely devoid of oxygen. Of the Great Lakes, only Lake Erie showed the low dissolved oxygen content in the hypolimnion (Beeton, 1969).

The deficit is more pronounced in stable lakes where wind velocity and current patterns do not upset the equilibrium. If the above factors are present, then it is imperative that the rate of oxygen depleted in the hypolimnion be

measured. In northern Europe, Strøm, in 1931 (according to Rodhe, 1969), was the first to attempt to obtain numerical data as an indication of the rate of organic matter supplied to lakes. He introduced the daily loss of oxygen per unit area of the hypolimnion as a measurable parameter.

Edmondson et al. (1956) and Edmondson (1967) measured the rate of development of the oxygen deficit for Lake Washington, Washington. Hutchinson (1938) and Rawson (1942) found that this rate was roughly proportional to the mean standing crop of net plankton in the epilimnion. However, because "increased phytoplankton may result in increased transport to the hypolimnion out of proportion to theassimilation by the zooplankton, the oxygen deficit will probably be more closely related to productivity than to standing crop" (Edmondson et al., 1956).

In open estuarine environments, the fluctuating conditions created by tides and river currents make it difficult for an oxygen deficit in the hypolimnion to become established. However, in semi-enclosed areas, e.g., protected harbours, where more stable conditions prevail, such a deficit can exist. In the Chesapeake Bay area, Carpenter et al. (1969) noted that oxygen depletion occurred in the upper Bay and in the adjacent Potomac estuary. Patten et al. (1963) observed extremely low oxygen concentrations in the lower section of

the same bay. Ketchum (1969) in a study of the Hudson River estuary, measured oxygen deficit at stations along the lower river and extending into the sea. An attempt was made by Welch (1968) to correlate dissolved oxygen and oxygen production with phytoplankton production at stations along the Duwamish River and estuary, Washington.

Occasionally, the oxygen saturation of waters can be a more meaningful parameter to measure. In a study in the Netherlands, Wibaut and Moens (1957) observed the oxygen saturation percentages at various depths from the harbours at Ijmuiden and extending through the locks of the Noordzeekanaal to Amsterdam. They suggested a general correlation between the percentage oxygen saturation and water quality:

0 - 20%	heavily polluted
20 - 40%	strongly "
40 - 60%	moderately "
60 - 80%	lightly "
80 -100% and more	not "

In his analysis of diurnal oxygen curves, Odum (1960) discussed the undersaturated oxygen values in the surface waters of the boat harbour of Corpus Christi, Texas.

Sills, characteristic of fjords, provide natural situations in which the stability of the deeper layers of water can be established. The sills effectively trap the water so that oxygen may become depleted in the bottom layers during the warmer summer months, as occurs on the west coast of North

America, e.g., Puget Sound (Barnes and Collias, 1958). A typical fjord in British Columbia, Indian Arm, had an oxygen distribution which ranged from 250% at the surface to 10% at the bottom (Gilmartin, 1964). On the east coast, in Bedford Basin, Nova Scotia, a comparable situation is made possible by the Halifax Harbour channel which constitutes a sill depth of 20m (Platt et al., 1970).

Data from the surveys in the Oslo Fjord, especially from the inner basin around Oslo, provide comparisons with the material in this present study. The depletion of oxygen at the lower levels could not be attributed solely to the sills of the fjord. Braarud (1953) noted that aeration of the deeper strata of large fjords, other than the Oslo, was satisfactory. Correlations between the oxygen content of the water column and the phytoplankton are discussed in detail in Braarud (1945), Braarud and Bursa (1939) and Braarud and Ruud (1937).

Transparency

Another of the early parameters used in measuring trophic levels was transparency. The great biological activity, characteristic of eutrophy, produces changes in color and turbidity, decreasing the amount of light penetrating the upper layers. The simplest, and perhaps the most common way to measure transparency is by the use of the Secchi disc; this technique has been used in the present study. However, the

method is quite subjective, and is also affected by physical conditions such as the glare of sun and wave action (Beeton, 1957). Non-biological turbidity and water color also adversely affect the Secchi disc readings.

In a classical study on illumination, Poole and Atkins (1929) analysed data to derive an equation correlating extinction coefficient per meter of visible light (λ) with depth (D) in meters:

$$\lambda = \frac{1.7}{D}$$

These workers also concluded that, within wide limits, the visibility of the disc is independent of the illumination in air. Using photometer, Secchi disc and water color readings, an extensive statistical study by Graham (1966) showed excellent correlation between disc observations and extinction coefficients.

Secchi disc observations become more meaningful when the values have been continuously recorded over a period of years. Documented studies exist to support this fact. A study of Lake Haruna, Japan showed that disc readings decreased 7.2m in 24 years. Yoshimura (1933) concluded that the lake was becoming eutrophic. Findenegg (1965b) described a similar study in Lake Klopeiner, Austria, where the decrease in 32 years was 3.8m. Lake Washington, Washington, in 51 years, had undergone a 3m change in mean Secchi disc readings from June to September (Edmondson, 1967). Lake Zürich has also been the

object of an intensive study from 1905-1928 by Minder; in 23 years the decrease had been 1.7m (Fruh et al., 1966).

Willén (1959) found a correlation between transparency and the annual spring and autumn turnover of the water column; minimum visibility occurred when the circulation pattern developed.

An attempt was made to determine the existance of a correlation between Secchi observations and biological production. Beeton (1965) concluded that such a correlation did not exist. In comparing the measurements of Goerges Bank phytoplankton populations and Secchi disc readings, Clarke (1946) demonstrated a significant relationship between the two. Riley (1956), using Poole and Atkins'extinction coefficient formula, came to the same conclusion in a similar study in Long Island Sound. However, his observations were made under optimal conditions, namely, away from land-derived particulate matter and during the spring flowering.

Sometimes Secchi disc determinations can give insight into the annual standing crop of phytoplankton (Jónasson and Mathieson, 1959). They showed that transparency was reduced by half during the spring and late summer blooms. In plotting the Secchi disc depths against the log of mean cell numbers, Hasle (1969) found a high negative correlation.

However, when those stations which contained a great quantity of "monads and flagellates" and coccolithophores were omitted, the disc readings were fair estimates of diatom abundance. Atkins et al. (1954) found a good inverse relationship between the amount of phytoplankton, as determined from chlorophyll extracts, and the Secchi disc range, except when vertical mixing brought suspended inorganic matter to the surface. Hart (1962) found that zooplankton did not affect the Secchi disc readings, and that there was good correlation between plant pigments and disc readings. Smayda (1963) found that Secchi disc regressions reflected the magnitude of phytoplankton abundance.

Turbidity, as measured by transparency, need not be a function of biological activity. One can not distinguish, by transparency, between natural and industrial particulate matter, as Beeton (1969) observed in the Great Lakes. Both types of particulate matter are especially prevalent in estuaries where they can greatly reduce illumination intensity and consequently, biological production. Williams (1966) calculated extinction coefficients from Secchi disc readings along the Outer Banks off the North Carolina coast and found they were dependent on river effluents and bottom mud sediments. He could not determine an obvious seasonal cycle correlated with the phytoplankton standing crop. Patten et al. (1963), in a study of lower Chesapeake Bay, computed extinction coefficients

obtained colormetrically from optical densities. Again, no seasonal trends were found.

Seasonal vertical distribution of the phytoplankton can be another factor adversely affecting the Secchi disc-production correlation, as discussed by Marshall and Orr (1928). During the spring blooms in shallow water, phytoplankton can become more concentrated near the bottom than anywhere else, while during the winter they can become more concentrated at the surface.

Standing Crop

As eutrophication progresses, the increase in the concentration of plant nutrients naturally leads to an increase in algal production. Frequently, the biomass or standing crop is used to establish the trophic level of any body of water. However, since standing crop is a measure of the quantity of phytoplankton at a given time, it is a static phenomenon. It may also be considered unsatisfactory, theoretically, since it measures the effects of biological production, not the rate of production (Vollenweider, 1969a). Gilmartin (1964) clarified the situation in his definition of standing crop: "an expression of the density of the population resulting from a balance between the population's growth and depletion".

The total standing crop can be misleading in comparing

two areas where inputs and losses of energy are of different orders of magnitude (Walsh, 1969). In comparing the standing crop of bodies of water under varying environmental conditions, errors arise in the deductions. A lake, eutrophic in summer, may have in winter under ice cover, a standing crop that is similar to an oligotrophic lake which is not covered with ice (Vollenweider, 1969a). Consequently, seasonal changes in the environment must be considered in determining the trophic state.

Another inherent problem emerges in interpreting the trophic level from biomass. Biomass, as commomly measured, does not take into account the extent of the trophogenic layer where production takes place. Ideally, the productive layer should be determined by indirect methods, e.g., light gradients, and the biomass calculated within this layer.

The standing crop can be related to primary productivity and the trophic levels. Vollenweider (1969a) has endeavoured to quantify this relationship by extracting the following data from the literature:

Trophic State of Lake	Plankton Density (cm^3/m^3)
ultra-oligotrophic	< 1
mesotrophic	3-5
ultra-eutrophic	>10

Regardless of the apparent problems, standing crop has proved a useful parameter to measure. Davis (1964), in compiling

data on Lake Erie, found a consistent increase in the average phytoplankton concentration from 1923-1963, and interpreted it as evidence for eutrophication. Findenegg's (1965a) study of a series of oligotrophic to eutrophic lakes showed no general correlation between trophic level and standing crop (wet weight). However, three eutrophic lakes in his study did contain proportionately larger algal biomasses, and one eutrophic lake had a large algal population only in summer. He also concluded that in most cases there was an inverse correlation between standing crop and primary production (carbon assimilation).

Holsinger (1955), in comparing the algal volumes of three Ceylon lakes noted that Beira Lake had 2 to $2\frac{1}{2}$ times more plankton in the summer months; its eutrophic state was attributed to the domestic drainage from city slums. In their review of the literature, Straškraba and Straškrabová (1969) reported that eutrophication was the result of a substantial decrease in the water level of Lake Seven,in the Soviet Union, for irrigation and hydro-electric development. The phytoplankton standing crop had doubled from 1947-1957. Anderson reviewed the change in the trophic nature of Lake Washington, and during the late summer, he noted an increase in epilimnic algal volume of the order of $2\frac{1}{2}$ to 3 times from 1950-1956 (Fruh et al., 1966).

An important work by Pavoni (1963) showed the following standing crops (as mean volumes) for seven Swiss lakes of varying trophic levels:

Brienzersee	oligotrophic	5.5 mm^3/cm^2
Thunersee	"	3.0
Walensee	"	9.0
Sempachersee	eutrophic	6.0
Zürichsee	"	3.8
Hallwillersee	"	13.8
Pfaffikersee	highly "	16.4

Since these mean volumes include both the nanno- and the net plankton, this study is probably more significant than most works in this field. On the basis of this data, Vollenweider (1969a) concluded that the standing crop was not a definitive criterion in determining trophic levels since the mean volume for the Walensee was no lower than those for the Hallwillersee and the Pfaffikersee. It appears that the discrepancy in interpreting these data lies in the low volumes of the eutrophic Sempachersee and the Zürichsee. The field work was undertaken during the autumn so that a possible reason for this discrepancy may be related to environmental conditions. Perhaps the thermocline of the two eutrophic lakes was not broken down, and the accumulating bottom nutrients were not recycled to the surface layers to increase phytoplankton production. Perhaps the data should have been based on annual mean volumes. Furthermore the effects of grazing are not considered; neither are the varying volumes of the epilimnion. Nevertheless, it seems that an increasing standing crop is not always indicative of progressive eutrophication.

The nutrient enrichment of some lakes does not necessarily lead to an equivalent increase in algal populations. Lund

(1969), in a comparison of seven English lakes and reservoirs, found that the state of eutrophication was not always evident from diatom abundance. He did recognize the fact that the Cyanophyceae were usually the most abundant algae in eutrophic waters, but that diatoms were indeed more relevant to eutrophication in British reservoirs. Findenegg in 1942, and Ruttner in 1937, reached the conclusion that the standing crop below a unit area in both oligotrophic and eutrophic lakes were of the same order of magnitude (Vollenweider, 1969a).

The standing crop in estuaries is usually much higher than in the adjacent coastal waters, primarily because of the stabilization of the water column and the higher concentrations of nutrients (Hobson, 1966). However, estuaries can also be subject to factors which decrease production in the form of inorganic industrial effluents and increased turbidity.

A station located in a small estuary of Narragansett Bay, Rhode Island, had a standing crop almost double that of two stations located near the entrance to Block Island Sound. Its highly eutrophic nature was attributed to excessive land drainage and the limited exchange of water between the estuary and the bay proper (Smayda, 1957). Basu et al. (1970) found that the standing crop (cells/l) was higher for the unpolluted Matlah estuary than for the polluted Hooghly estuary, India. These findings can be explained on the basis of the detrimental

effects of toxic effluents from several industries situated along the Hooghly River.

The annual standing stock of phytoplankton, as measured by chlorophyll concentration, in Bedford Basin, Nova Scotia is ten times that in nearby St. Margaret's Bay. A similar difference was also noted in the primary production rates. These discrepancies are related to the higher nutrient concentrations in Bedford Basin, derived from the untreated sewage effluent from the Halifax area (Platt et al., 1970). The standing crop, as indicated by chlorophyll determinations, has been used to measure the extent of eutrophication in the River Tyne, England (James and Head, 1970). It was found that the high nutrient supply, derived mainly from untreated sewage and runoff and concentrated in the river plume, supported a higher standing crop in this area than in the adjacent coastal waters.

Braarud and Bursa (1939) and Braarud (1945) demonstrated a definite difference between the plankton concentrations inside Oslo Harbour and in the outer part of the Fjord, especially during the summer months when the rich populations were recorded near the city. The difference was attributed to the fertilizing effect of sewage.

Indicator Species

The quantitative increase in biomass, typical of incipient eutrophication, is "usually accompanied at the outset by a decrease in the number of species typical of oligotrophic waters and, simultaneously or subsequently, by the appearance of indicator species in the plant communities" (Vollenweider, 1969a).

In using indicator species as a measure of the trophic level, it is imperative that the seasonal dominant species be determined. Thus,during a spring bloom, diatoms may be indicators, while during a late summer bloom, blue-greens usually predominate (Rawson, 1956). Rawson also suggested that the total number of cells in a sample may be less significant than the number of cells of a dominant species in that sample.

In small, wind-sheltered lakes that are subject to eutrophication certain blue-green algae will appear as the "bloom" species, since these species contain gas vacuoles enabling them to remain at the level of maximum light intensity. In those lakes subject to high winds, turbulence makes possible the development of heavier algae such as the diatoms, as the "bloom" species (Findenegg, 1965a).

For the inner Oslo Fjord, Braarud (1945) was reluctant to classify species according to their relationship to polluted water, partly because of the continuous supply of phytoplankton

made possible by circulation. Stations located in polluted areas contained the same species as those in unpolluted areas, and also had predominant species which were typical of the open sea. He states "how relatively unimportant the pollution factor is for the qualitative composition of the phytoplankton". Contrary to Kolkwitz and Marsson's (1908) freshwater classification according to which dinoflagellates are virtually all oligosaprobic, dinoflagellates in Oslo Fjord are relatively abundant in the polluted regions.

Table I gives a list of some phytoplankton species which are indicators of trophic levels in various environments.

Table I. Examples of trophic indicator phytoplankton species, as selected by various authors.

PHYTOPLANKTON SPECIES

LOCATION	OLIGOTROPHIC	MESOTROPHIC	EUTROPHIC	SOURCE
various locales, freshwater	Staurastrum Tabellaria Cyclotella Dinobryon		Oscillatoria rubescens Anabaena spp. Aphanizomenon flos-aquae Microcystis aeruginosa Melosira sp. Fragilaria sp. Stephanodiscus sp. Asterionella sp.	Sawyer, 1966
various locales, freshwater			Fragilaria crotonensis	Vollenweider, 1969
Linsley Pond, Connecticutt Lake Windermere, England			Melosira italica Asterionella formosa Asterionella Synedra	Hasler, 1947
Blelham Tarn, Queen Elizabeth II Reservoir, King George VI Reservoir, England			Asterionella formosa	Lund, 1969
Irish loughs			Asterionella formosa Ceratium hirundinella	Round & Brook, 1959
Lough Neagh, Ireland			Oscillatoria tenuis Gomphosphaeria sp. Anabaena	Govn't N. Ireland, 1968
Lake Constance Walensee Klopeiner other Swiss and Austrian lakes	Cyclotella Rhodomonas chrysomonads		Anabaena Microcystis Oscillatoria Tabellaria Melosira	Findenegg, 1965
Lake Zürich, Switzerland			Oscillatoria rubescens	Pavoni, 1963

(Cont'd)

TABLE I (Cont'd)

PHYTOPLANKTON SPECIES

LOCATION	OLIGOTROPHIC	MESOTROPHIC	EUTROPHIC	SOURCE
700 Swedish lakes	Tabellaria flocculosa v. pelagica Dactylococcopsis ellipsoides desmids	Kirchneriella lunaris chlorococcales	Fragilaria crotonensis Melosira granulata	Teiling, 1955
Alster Lake, Germany			Aphanizomenon flos-aquae Stephanodiscus hantzschii	Caspers, 1964
Lake Mälaren, Italy western eastern	Mougeotia sp.		Oscillatoria tenuis	Willén, 1968
Lake Ontario central shore	Melosira islandica Asterionella fromosa		Stephanodiscus tenuis	Nalewajko,1966
Lake Michigan			Stephanodiscus hantzschii " binderanus Tabellaria Fragilaria Asterionella	Gerstein, 1965
Lake Michigan central shore	Melosira islandica		Melosira ambigua	Holland, 1968
western Canadian lakes	Asterionella formosa Melosira islandica Tabellaria fenestrata " flocculosa Dinobryon divergens Fragilaria capucina Stephanodiscus niagarae Melosira granulata Staurastrum spp.	Fragilaria crotonensis Ceratium hirundinella Pediastrum boryanum " duplex Coelosphaerium naegelianum Anabaena spp. Aphanizomenon flos-aquae Microcystis aeruginosa	Microcystis flos-aquae	Rawson, 1956

TABLE I (Cont'd)

PHYTOPLANKTON SPECIES

LOCATION	OLIGOTROPHIC	MESOTROPHIC	EUTROPHIC	SOURCE
Muir Lake, Alberta	Dinobryon		Microcystis aeruginosa Aphanizomemon flos-aquae	Bozniak & Kennedy, 1968
Ohio River	Cryptomonas Chrysococcus		Euglena Trachelmonas Phacotus	Brinley, 1942
lower Hudson River			Tabellaria Lyngbya Oscillatoria Melosira	Howells et al., 1970
various locales, streams			Euglena Oscillatoria	Patrick, 1965
Lake Washington, Washington			Oscillatoria rubescens	Edmondson et al., 1956
Lake Maggiore, Italy			Tabellaria fenestrata Oscillatoria rubescens	Bonomi et al., 1968
Indian lakes			Microcystis aeruginosa	Singh, 1953
Potomac estuary			Microcystis aeruginosa	Carpenter et al., 1969
Potomac estuary			Pediastrum Scenedesmus Ankistrodesmus Stephanodiscus Melosira Synedra Anabaena Nostoc Oscillatoria	Shapiro & Ribeiro, 1965

TABLE I (Cont'd)

LOCATION	PHYTOPLANKTON SPECIES			SOURCE
	OLIGOTROPHIC	MESOTROPHIC	EUTROPHIC	
			Coccolithus huxleyi	Braarud, 1957
	Nitzschia delicatissima	Skeletonema costatum Pontosphaera huxleyi Ceratium fusus " tripos Peridinium trochoideum	Eutreptia lanowi	Braarud & Bursa, 1939
Oslo Fjord, Norway	Ceratia		Peridinium triquetrum Eutreptia lanowi Carteria sp. Chlamydomonas sp. Pontosphaera huxleyi	Braarud, 1945
	Skeletonema costatum Chaetoceros wighamii			Lavender, 1918

DESCRIPTION OF THE INVESTIGATED AREAS

St. John's Harbour

This is a well-developed natural harbour (Figure 3), servicing a population of 86,290[1] in St. John's and 7,211[1] in Mount Pearl. On the north side of the harbour, just below Signal Hill, lies a small fishing community, the Lower Battery. Fish offal, dumped from about a dozen fishing stages located here, contributes to the plant-nutrient supply of the harbour. Farther along the shore are a series of berthings and main docking areas. On the south side are the docks of four major oil companies. Boats, especially oil tankers, contribute to petrochemical pollution of the harbour; occasionally, the tankers are responsible for substantial oil slicks. Also of interest is the municipal, auxiliary, steam-generating plant, which uses harbour water as a coolant, and is therefore a possible source of thermal pollution. Additionally, on the south side of the harbour, washings from the salt fish-processing plant flow into the harbour, although the offal is trucked away from the plant.

Effluents from minor processing operations, such as secondary wood-processing, animal feed-processing and steel-manufacturing feed into the Waterford River, which flows into

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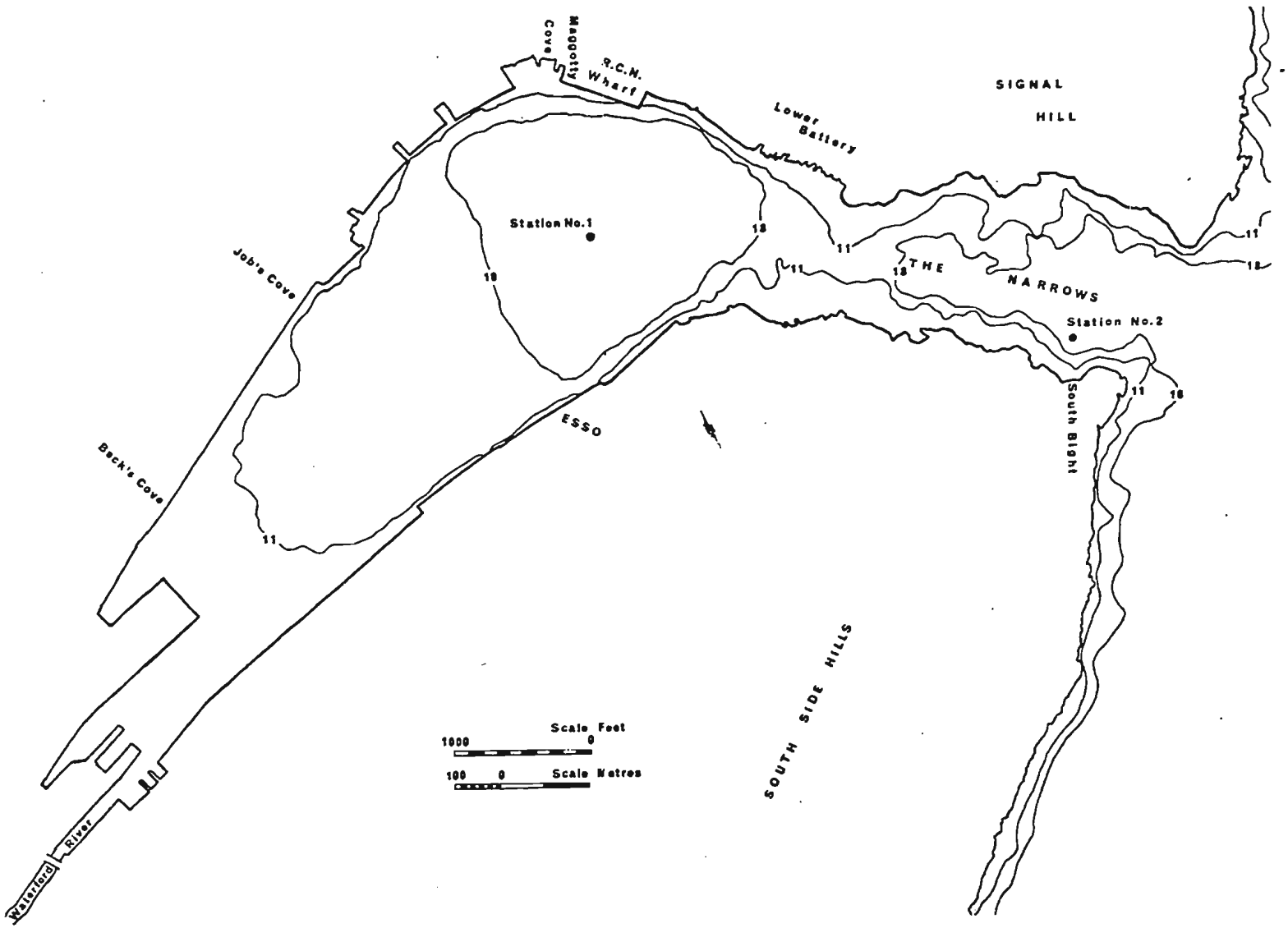
1. 1971 census

Figure 3. Map of St. John's Harbour showing depth (m) and location of sampling stations.


Cove
Masonic
R.C.N.
Wharf
Lower
Battery
SIGNAL
HILL
Station No.1
18
11
Job's Cove
THE
NARROWS
Station No.2
South Bight
Back's Cove
ESSO
SOUTH SIDE HILLS
Scale Feet
1000
0
100
0
Scale Metres
Waterford
River

the inner end of the harbour. Brewing and margarine-manufacturing effluents feed into the city storm sewers, and thence directly into the harbour.

The major source of organic pollution, which is of central concern here, is the runoff of untreated human waste and storm sewage directly into the harbour.

The drainage area of St. John's Harbour includes two geological formations of the Cabot Group deposited in late PreCambrian (Rose, 1952). The St. John's Formation stretches along the north side of the harbour to the bottom of Signal Hill, and is composed mainly of black slate and argillite. The Signal Hill Formation extends along the south shore and both sides of the Narrows. There are three transitional beds of sedimentary rocks here: grey-green sandstone with weathered brown surfaces, red sandstone most prominant along the steep cliffs of the Narrows, and red conglomerate with mauve-colored, weathered surfaces.

Characteristic of the eastern coastline is the semi-parallel arrangement of the faults and folds in a north and northeasterly pattern. Of less significance is a perpendicular stress pattern from the north-west. At St. John's Harbour a northerly fault exists which follows the coastline on both sides of the harbour within the Signal Hill Formation. Also, there are two north-west fault planes: one originating at

the junction of the two formations at the edge of the harbour; the other about a mile up the Waterford River.

On the north side of the Narrows, Signal Hill rises to an elevation of 500 feet (152m), while along the south side, the South Side Hills rise to 650 feet (198m), but with a more gradual slope. Apparently this difference in height is the result of a glacier moving inland and scraping off the top of Signal Hill, leaving boulder erratics and creating a sheer cliff, while few evidences of glaciation are apparent on the opposite side.

The Waterford River is the only large, overground river flowing into the harbour. The glacial-formed ponds on both Signal Hill and the South Side Hills do not drain into the harbour; the ponds in St. John's proper are within the Quidi Vidi watershed.

The entrance of the harbour faces to the south-east, but bends due west about half-way in. The length of the harbour from the one foot (.30m) water mark is 3178m (1.9mi); its widest section is 691m (.43mi). The greatest depth, 29.6m (16.2 fathoms), is found in the middle of this section; Station No. 1 is located here. Outside the main basin, in the Narrows, the depth decreases to 11m (6 fathoms). Thus the Narrows constitutes a sill for the harbour proper. Just inside the harbour entrance is another smaller basin with a width of

436m (.27mi) and a depth of 28.3m (15.5 fathoms). Station No. 2 is located here, but lies closer to the southern shore where the depth is 26.8m (14.7 fathoms).

The mean tide range is .85m (2.8ft) and the large tide range is 1.5m (5.1ft).

Originally, raw sewage flowed into ditches and open streams which emptied into several coves along the waterfront. In the 1880's and 1890's, domestic plumbing was introduced, and some of the streams were diverted underground into sewer mains. Gradually a sewage collecting system was constructed and over the years it has come to consist of two main outlets for sanitary and storm sewage. The system in the northern and eastern sections of the city drains into a large holding tank at Job's Cove. Drainage from the central and western sections of the city, as well as from Mount Pearl, flows into another holding area at Beck's Cove. Here a pumping station diverts the sewage to Job's Cove, where it is periodically released into the harbour. Future plans include the construction of a new holding tank at Maggotty Cove from where all St. John's and Mount Pearl sewage would be pumped to a treatment plant at the head of Quidi Vidi Lake, thence into pipelines leading out through Quidi Vidi Gut. This would greatly reduce the load on St. John's Harbour.

A history of dredging in the harbour dates back to the

late 1880's. From 1956-1965, the Harbour Development Board, under the auspices of the Federal Department of Public Works, undertook extensive dredging at the head of the harbour and along the northern waterfront in the construction of piers. The bottom of the harbour is covered with sludge deposits, and presumably, in the central basin, these were not removed during dredging. No dredging was carried out during the course of this study.

Aquaforte Harbour

Being relatively unpolluted, Aquaforte Harbour (Figure 4) was chosen as an area for comparison in this study. It is located approximately sixty miles (97 kilometers) south of St. John's Harbour on the eastern coastline (referred to as the "Southern Shore"). Its population of 206[2] lies along the inner half of the northern shore. All the fishing stages are located within a small gut at the head of the harbour. This is an area of relative stagnancy; consequently, any enrichment would be concentrated along this section of shore.

The shores of the harbour are a series of sandy beaches hidden among twenty foot high cliffs. In Recent times these cliffs had been marine beaches (Rose, 1952). Most of the harbour

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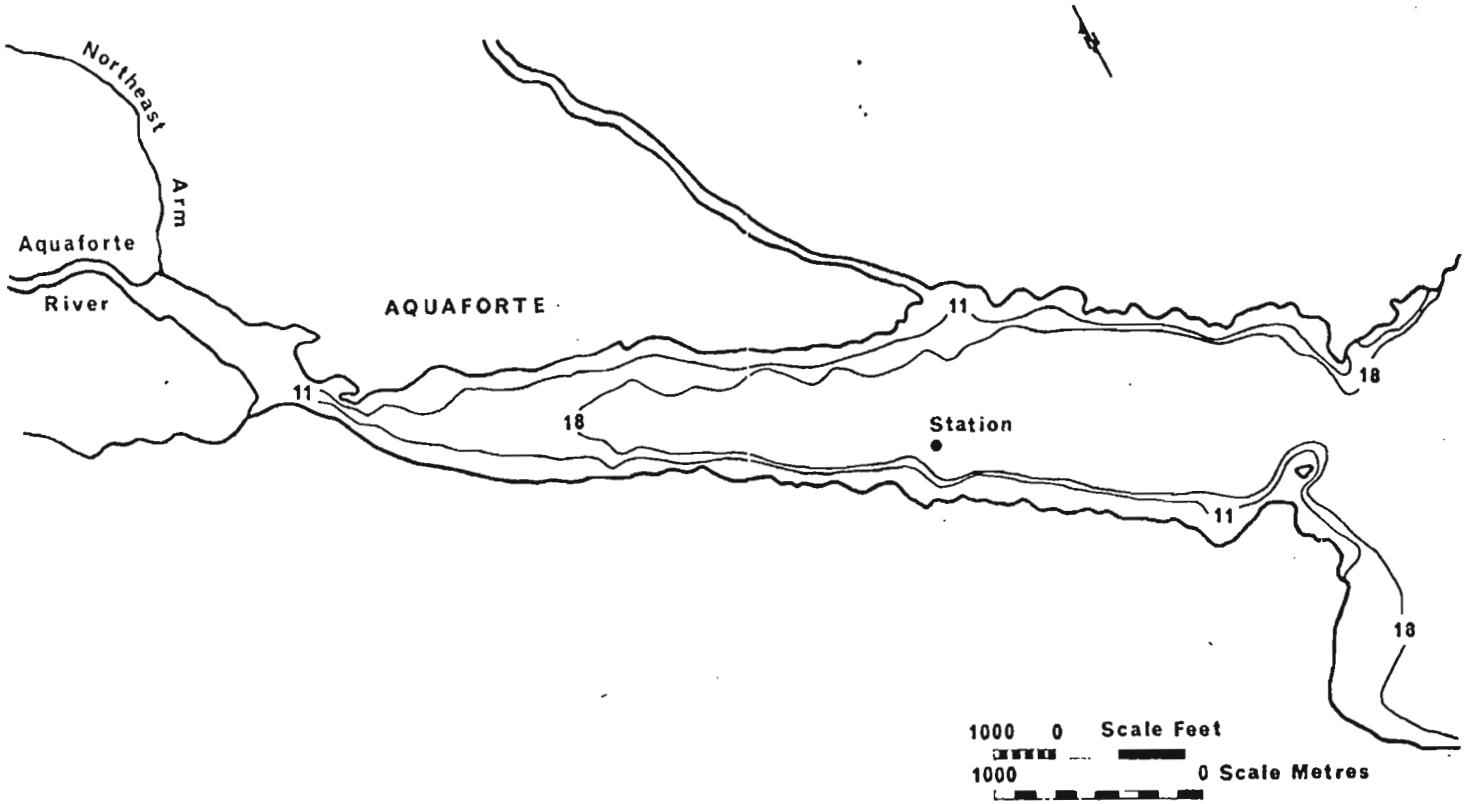
2. 1966 census

Figure 4. Map of Aquaforte Harbour showing depth (m) and location of the sampling station.


Northeast Arm
Aquaforte River
AQUAFORTE
11
18
Station
11
18
11
18
1000 0 Scale Feet
1000 0 Scale Metres

lies within the "Torbay slate" section of the Conception Group, characterised by mid-PreCambrian green sandstone, siltstone, slate, quartzite and conglomerate. However, the headlands at the harbour entrance are part of the St. John's Formation, already mentioned.

The hills on either side of the harbour are relatively steep, but are lower than those at St. John's Harbour, having an elevation of approximately 300 feet (91m). Two main rivers flow into the harbour: Aquaforte River located at the head of the harbour, and an unnamed river located halfway along the northern shore. At the mouth of the latter is a twenty foot falls. The sampling station is situated across from this falls, but closer to the southern shore away from the influence of fresh water. A small stream, Northeast Arm, also enters the harbour near Aquaforte River.

At Aquaforte Harbour there is a typical northeast fault plane crossing the mouth of Aquaforte River. Perpendicular to this in a north-west direction are two additional faults following the beds of the two main rivers.

The entrance of the harbour faces to the southeast. The harbour itself is straight and relatively narrow; the length from the one foot (.30m) tidal mark is 5715m (3.5mi), and the width is 1022m (.63mi). The greatest depth, 23.8m

(13 fathoms), is found in the centre of the harbour. However, towards the entrance there is a gradual increase in depth to 27.4m (15 fathoms). There is no sill at the entrance so the water circulates freely.

The mean tide range is 1.01m (3.3 ft) and the large tide range is 1.55m (5.1 ft).

MATERIALS AND METHODS

Field Work

Two stations were sampled in St. John's Harbour: one in the middle of a sighting from Steers Wharf and the Royal Canadian Navy Wharf, 47° 34' 00" N 52°41' 45" W; the other on the south side of the Narrows just off South Bight, 47° 33' 50" N 52° 41' 55" W(Figure 3). The station in Aquaforte Harbour was situated off the southern shore across from the falls at 47°00' 10" N 52° 55' 40" W (Figure 4).

Monthly field trips were made from June, 1969 to August, 1970. However, from December to April no field trips could be made to Aquaforte Harbour because boats were not available during the winter months. Nevertheless,samples were taken from St. John's Harbour in February and March, but only the physical data were analysed since no comparable biological data was obtained from Aquaforte Harbour. Both areas were visited as close together in time as possible, usually within two days, occasionally within three.

Water samples were taken from four depths: surface, 5, 10 and 22 meters. Using a 3 liter Kemmerer sampler and later a 2 liter Nansen bottle, subsamples for salinity, for oxygen and for biological analysis were taken from each depth. Temperature was measured with a thermistor from a YSI 51 oxygen meter at the above depths. On one occasion the Hartek

DOA meter was used to measure temperature and salinity, but the salinity readings were not as accurate as those from the titration method. These salinity recordings were taken during the winter months when the salinity was fairly uniform at all depths; the meter did not distinguish small differences in salinities. Secchi disc readings were also taken at all stations. Horizontal surface tows with a #20 plankton net (pore size,76μ) were taken at each location.

Laboratory Analysis

Oxygen

Water samples for oxygen, taken in ground-glass-stoppered bottles and preserved in the field with manganese sulfate and potassium hydroxide, were analysed by a simplified Winkler method, as outlined in Welsh and Smith (1949) and the U.S. Navy Hydrographic Office Publication No. 607 (1955). The Alsterberg modification, the addition of sodium azide to the alkaline hydroxide, was used, as recommended in the American Public Health Association (1955), for waters high in organic matter. Titrations were carried out within 24-48 hours after collection. The percentage saturation of oxygen was determined from Richards and Corwin's (1956) nomogram of oxygen solubility as a function of temperature and salinity.

Salinity

Salinities were determined by a simplified silver nitrate (Mohr modification), as outlined in Welsh and Smith (1949).

Initially, a five gallon sea water sample was taken from the running sea water system at the Marine Sciences Research Laboratory (MSRL), Logy Bay, and this was standardized against Eau de Mer Normale, 18.374°/oo chlorinity. The MSRL sample was then used as a secondary standard.

Secchi disc

Using the depths determined in the field, the extinction coefficient of visible radiation was calculated using Poole and Atkins' (1929) equation.

Phytoplankton

Phytoplankton samples were fixed with Lugol's solution (KI, 2g; I_2, 1g; distilled water, 100ml), to which 10ml of glacial acetic acid was added. This method of fixing was especially good for preserving the flagella and the shape of the nonsiliceous species. On one occasion an aqueous solution of Merthiolate and sodium borate (Weber, 1968) was used in an attempt to better preserve the internal structure of the cells. The internal structures, especially the chloroplasts, of the diatoms and the armoured dinoflagellates were clearly visible. However, the technique may not have preserved the unarmoured dinoflagellates, because too few of these were found. One distinct disadvantage of using the Lugol's solution is that coccoliths dissolve in the acetic acid.

Plankton samples were analysed as outlined in Lund,

Kipling and LeCren (1957) with the following minor modifications. Concentration of the plankton was carried out by settling in Utermöhl's chambers. Because of the paucity of phytoplankton, it was usually necessary to use two 100ml chambers. Even then plankton concentrations were not high enough to give statistically valid results. Therefore the procedure was altered to carry out settling in 500ml graduated cylinders, and approximately 350 to 450ml of the 500ml biological sub-sample was actually counted. Most of the previously-counted phytoplankton samples were recounted. After settling for a minimum period of four days, the supernatant was siphoned off at a rate of 30ml per minute. The sample was then resettled in 25ml Utermöhl chambers and examined under a Zeiss UPL inverted microscope. The phytoplankters were analysed both quantitatively and qualitatively. Identification in many cases was possible only to the genus level. Further identification was impossible without becoming involved in the preparation of high refractive index mounts, enrichment-culturing and electron microscopy.

Diatoms were identified using Lebour (1930), Huber-Pestalozzi (1942), Cleve-Euler (1951), Hendey (1964), Patrick and Reimer (1966), and Saunders and Glenn (1969). Dinoflagellates were identified using Paulsen (1908) Kofoid and Swezy (1921), Lebour (1925), Huber-Pestalozzi (1966), and Steidinger and Williams (1970). The publications of Taylor (1933; 1934), Huber-Pestalozzi (1941; 1961), Smith (1950), Davis (1955),

Trégouboff and Rose (1957), Massuti and Margalef (1960), Griffith (1961), Prescott (1961), Brunel (1962), Tsumura (1963), and Wood and Lutes (1967) were used for general identification.

Quantitative analysis of samples included the counting of individual species in a predetermined area on the surface of the chamber depending on their size and concentration. Where possible, the area was determined when approximately 100 cells were tallied; this has an accuracy of 20% (Lund, Kipling and LeCren, 1957; Uehlinger, 1964). Individual cells were counted in chain-forming colonies. Biomass was calculated by first measuring the dimensions of usually 25 random cells (Holmes et al., 1969) of a species, and then determining the mean cell volume by assuming equivalent geometric shapes characteristic of the species.

The cell volume was determined for each species at each depth and the mean cell volume for each location at each month was calculated. The mean cell volumes of five months data in 1969 were then analysed for significant differences in size, by calculating the F-statistic of a one-way analysis of variance. When the F-test showed no significant difference in cell volumes for each station, the mean of the means of all of the cell volumes was used in determining the biomass for 1969 and 1970. When the F-test showed a significant difference in size, the mean of the means of the cell volumes for the summer stations of 1969 was projected for the 1970 stations. Since the 1970 phytoplankton were primarily summer forms, it

was assumed that the mean cell volumes from the summer of 1969 could be projected for the following year. Species, infrequently observed, and those observed for the first time, were continuously measured throughout 1970.

Phytoplankton biomass and oxygen determinations were calculated under a square decimeter of surface area for a column 22m in depth, assuming that no photosynthesis occurred below that depth in St. John's Harbour, and that at Aquaforte Harbour the maximum depth was only 23m. The equation used was as follows:

$$\text{Biomass} = \frac{(A_1 + A_2)}{2} \cdot d_1 + \frac{(A_2 + A_3)}{2} \cdot d_2 + \frac{(A_3 + A_4)}{2} \cdot d_3$$

where:

A_1, A_2, A_3 and A_4 are the biomasses at depths 0, 5, 10 and 22 meters respectively;

and,

d_1 is the depth between A_1 and A_2; 50dm

d_2 is the depth between A_2 and A_3; 50dm

d_3 is the depth between A_3 and A_4; 120dm.

RESULTS

Salinity

Monthly salinity determinations were made from June to November, 1969 and from May to August, 1970 for all three stations. Additionally, determinations were made on February and March samples from St. John's Harbour (Figures 5,6 and 7; Table II).

Comparing the data from the two harbours, the station at Aquaforte had higher salinities than either station at St. John's. Of the two St. John's Harbour stations, No. 2 generally had higher salinities at the upper depths. At 22m, the highest salinities were recorded at No. 1. The salinities generally ranged from 31.00 to 32.70°/oo, increasing gradually with depth at all stations.

Especially low surface salinities were recorded at the two stations in St. John's Harbour in September: 26.54 and 27.44°/oo; and in February: 20.76 and 27.13°/oo. These low surface salinities were also recorded at all stations in November: 24.47 and 26.00°/oo at St. John's and 23.53°/oo at Aquaforte.

Some semblance of seasonal variation in salinity was discernable. In 1969, the highest salinities at all three

Figure 5. Seasonal variation in the salinity at the four sampling depths at Station 1, St. John's Harbour.

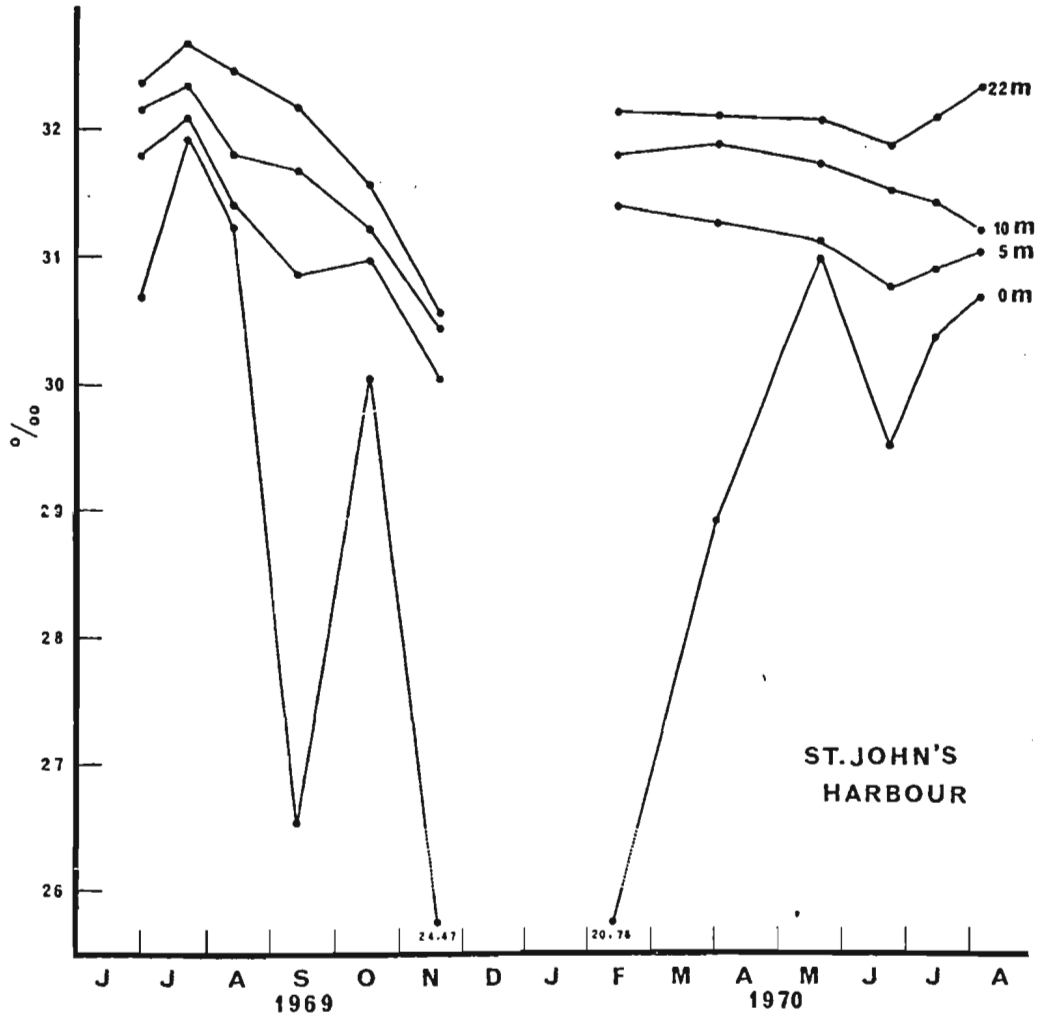

22m
10m
5m
0m
32
31
30
29
28
27
26
°/oo
24.47
20.76
J J A S O N D J F M A M J J A
1969
1970
ST.JOHN'S
HARBOUR

Figure 6. Seasonal variation in salinity at the four sampling depths at Station 2 (the "Narrows"), St. John's Harbour.

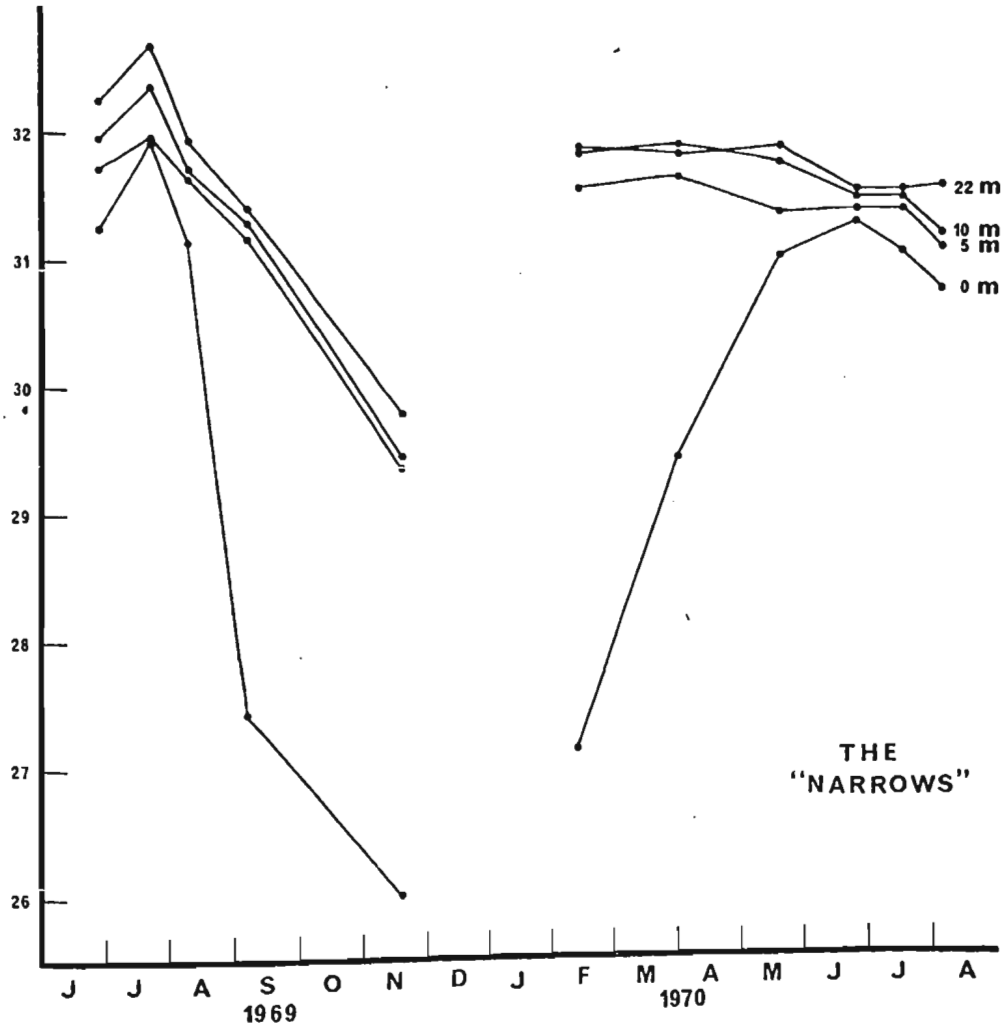

32
31
30
29
28
27
26
22 m
10 m
5 m
0 m
THE
"NARROWS"
J J A S O N D J F M A M J J A
1969
1970

Figure 7. Seasonal variation in salinity at the four sampling depths at Aquaforte Harbour.

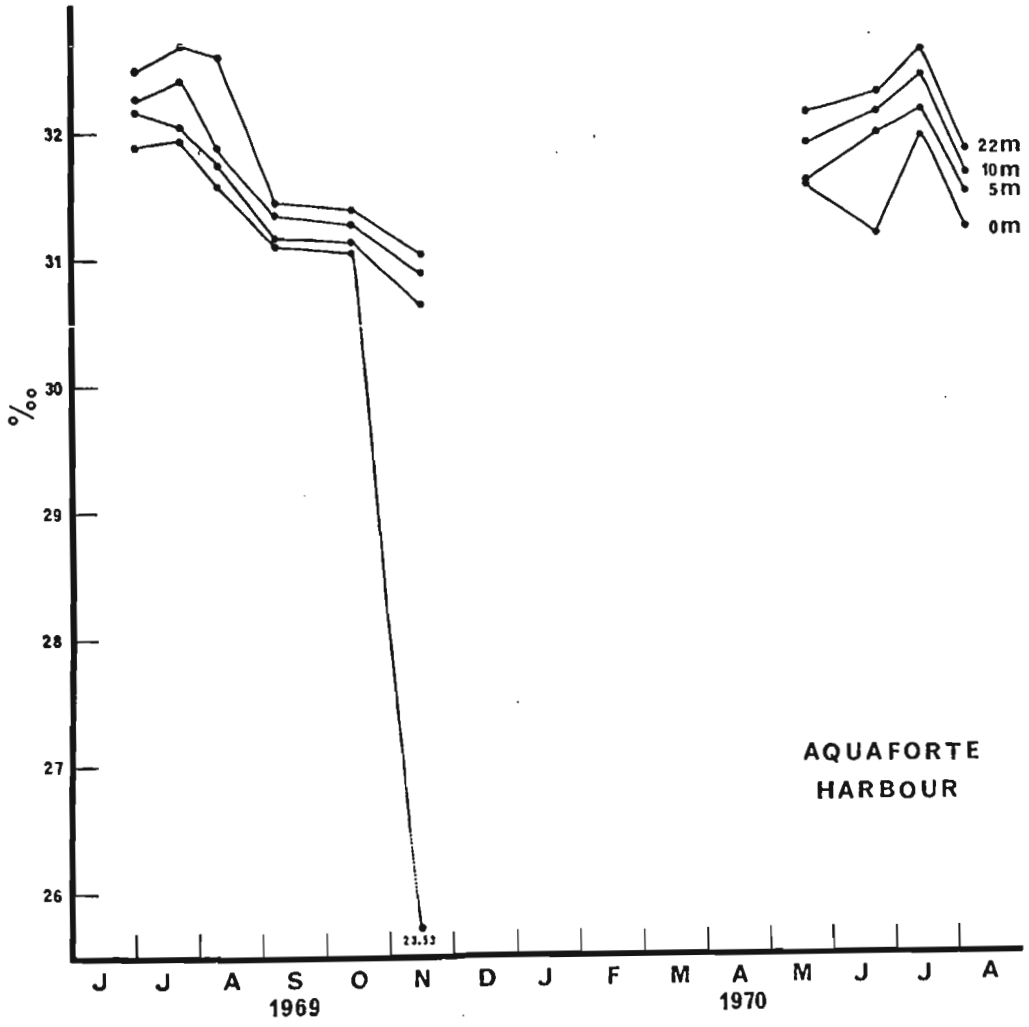

22m
10m
5m
0m
32
31
30
29
28
27
26
‰
23.53
J J A S O N D J F M A M J J A
1969
1970
AQUAFORTE
HARBOUR

Table II. Salinity data for St. John's Harbour and Aquaforte Harbour.

	1969						1970					
METERS	JUN	JUL	AUG	SEP	OCT	NOV	FEB	MAR	MAY	JUN	JUL	AUG
Station 1, St. John's Harbour												
0	30.68	31.92	31.23	26.54	30.06	24.47	20.76	28.95	31.04	29.56	30.42	30.73
5	31.79	32.08	31.41	30.87	30.98	30.06	31.44	31.32	31.18	30.82	30.96	31.10
10	32.15	32.34	31.80	31.68	31.23	30.46	31.84	31.94	31.79	31.58	31.48	31.27
22	32.36	32.67	32.46	32.18	31.58	30.58	32.18	32.17	32.13	31.94	32.17	32.41
Station 2, St. John's Harbour												
0	31.25	31.92	31.13	27.44	-	26.00	27.13	29.45	31.06	31.34	31.10	30.80
5	31.72	31.96	31.63	31.17	-	29.37	31.58	31.68	31.41	31.44	31.44	31.13
10	31.96	32.36	31.72	31.29	-	29.47	31.86	31.94	31.81	31.49	31.53	31.25
22	32.25	32.67	31.94	31.41	-	29.80	31.92	31.87	31.94	31.58	31.61	31.63
Aquaforte Harbour												
0	31.89	31.94	31.58	31.11	31.06	23.53	-	-	31.60	31.22	31.99	31.27
5	32.17	32.05	31.75	31.18	31.15	30.66	-	-	31.64	32.01	32.20	31.55
10	32.27	32.41	31.89	31.36	31.29	30.91	-	-	31.94	32.18	32.48	31.70
22	32.49	32.68	32.60	31.46	31.41	31.06	-	-	32.18	32.34	32.68	31.89

stations were recorded in July. This was followed by a continuous decrease until November when the lowest salinities were recorded. In 1970, no consistent pattern developed for all three stations. At Aquaforte Harbour the salinity increased, as in 1969, to a maximum in July. At St. John's Harbour another rise in salinity was noted in March; the summer maxima were more irregular, occurring in July and August at Station 1, and in June and July at Station 2.

Temperature

Water temperatures were taken at five depths at all stations in the summer and fall of 1969 and the spring and summer of 1970(Figure 8 and Table III). Data for the two stations in St. John's Harbour were supplemented by temperatures recorded in the holding tank at the MSRL, Logy Bay (note dotted line in A and B of Figure 8). An analysis of the laboratory temperatures showed that they were roughly comparable to those of the open harbour.

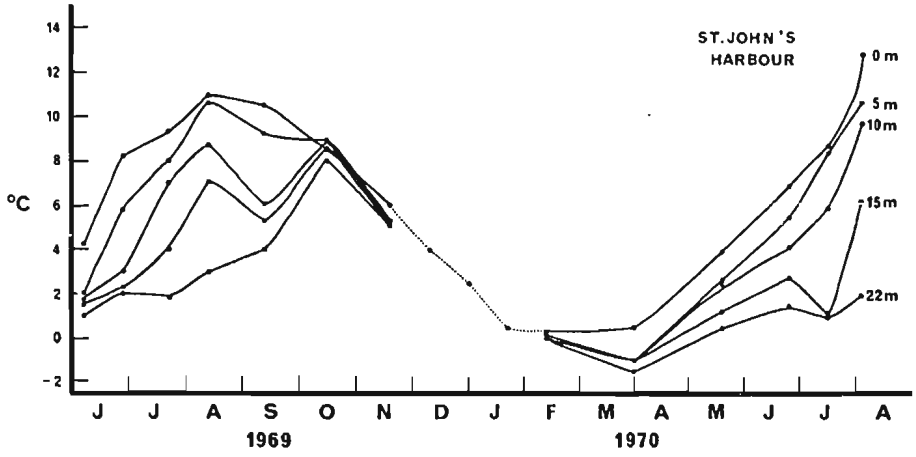
In comparing those months which were sampled in both years, the water temperatures rose higher in 1970 than in the previous year; this was especially evident in the surface waters of St. John's Harbour where the difference was greater than two degrees in August of the two years. Generally,

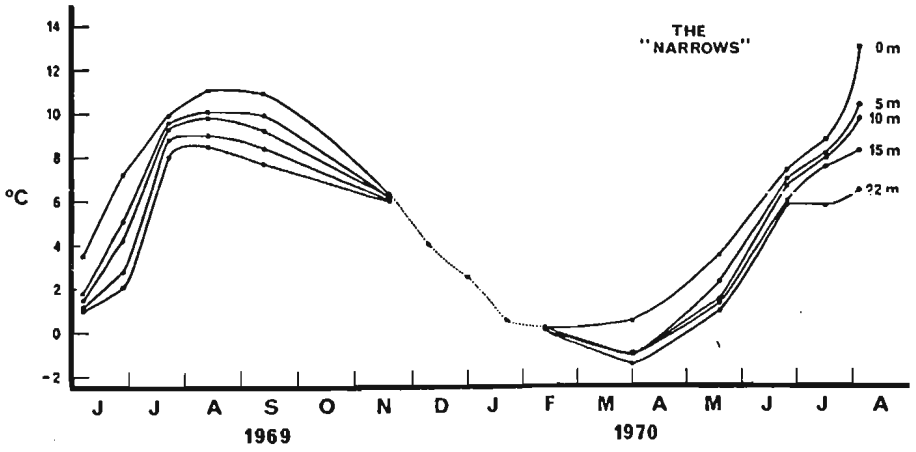
Figure 8. Seasonal variation in temperature at fives depths at :

A. Station 1, St. John's Harbour

B. Station 2 (the "Narrows"), St. John's Harbour

C. Aquaforte Harbour.


ST.JOHN'S
HARBOUR
0 m
5 m
10m
15m
22m
°C
14
12
10
8
6
4
2
0
-2
J J A S O N D J F M A M J J A
1969
1970


THE
"NARROWS"
0 m
5 m
10 m
15 m
22 m
°C
14
12
10
8
6
4
2
0
-2
J J A S O N D J F M A M J J A
1969
1970

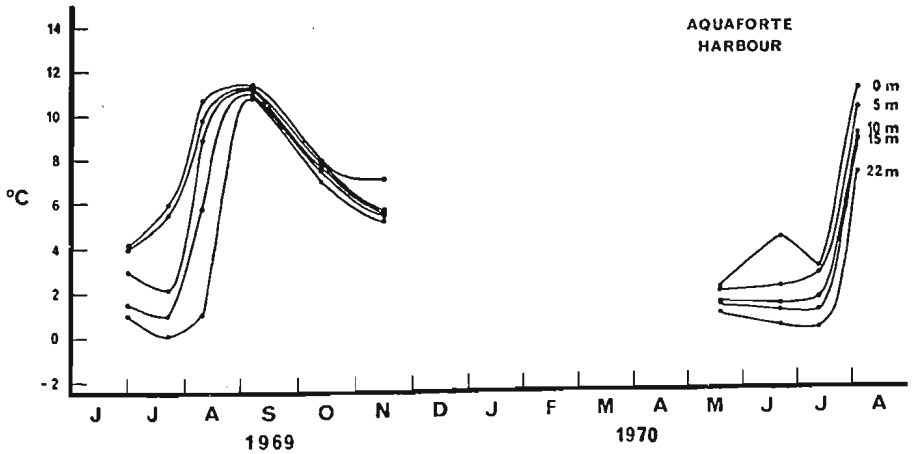

AQUAFORTE
HARBOUR
0 m
5 m
10 m
15 m
22 m
°C
14
12
10
8
6
4
2
0
-2
J J A S O N D J F M A M J J A
1969
1970

Table III. Temperature data for St. John's Harbour and Aquaforte Harbour.

METERS	1969 JUN	JUN	JUL	AUG	SEP	OCT	NOV	1970 FEB	MAR	MAY	JUN	JUL	AUG
Station 1, St. John's Harbour													
0	4.5	8.2	9.3	10.9	10.5	8.5	6.1	0.3	0.5	4.0	7.0	8.8	13.0
5	2.3	5.8	8.0	10.6	9.2	8.9	5.3	0.2	-1.0	2.7	5.6	8.5	10.8
10	2.0	3.0	7.0	8.7	6.1	8.8	5.2	0.2	-1.0	2.5	4.2	7.0	9.8
15	].5	2.3	4.0	7.1	5.3	8.6	5.2	0.0	-1.0	1.5	2.8	1.2	6.3
22	1.0	2.0	1.8	3.0	4.0	8.0	5.1	0.0	-1.5	0.5	1.5	1.0	2.0
Station 2, St. John's Harbour													
0	3.5	7.2	9.9	11.1	10.9	-	6.3	0.2	0.5	3.5	7.4	8.8	13.1
5	1.8	5.1	9.6	10.1	9.9	-	6.2	0.2	-1.0	2.3	7.0	8.2	10.4
10	1.5	4.2	9.3	9.8	9.2	-	6.2	0.1	-1.0	1.5	6.7	8.0	9.8
15	1.2	2.8	8.8	9.0	8.4	-	6.1	0.0	-1.0	1.3	6.0	7.6	8.3
22	1.0	2.1	8.0	8.5	7.7	-	6.0	0.0	-1.5	0.9	5.8	5.8	6.5
Aquaforte Harbour													
0	-	4.2	6.0	10.7	11.4	8.0	7.1	-	-	2.1	4.3	3.0	11.2
5	-	4.0	5.5	9.8	11.3	7.9	5.7	-	-	1.9	2.1	2.7	10.3
10	-	3.0	2.2	8.9	11.2	7.7	5.6	-	-	1.4	1.3	1.6	9.1
15	-	1.5	1.0	5.8	11.0	7.5	5.4	-	-	1.3	1.0	1.0	8.8
22	-	1.0	0.1	1.1	10.8	7.0	5.2	-	-	0.9	0.3	0.2	7.3

temperatures in St. John's Harbour were higher than those in Aquaforte Harbour; the exceptions were in September and November. Station 2 in St. John's Harbour usually had higher temperatures at all depths than Station 1.

The lowest surface temperatures were recorded in February at both of the St. John's stations: 0.2 C and 0.3 C. Otherwise, the lowest temperatures were recorded in March; at 22m, the reading was -1.5 C at the two stations. The highest temperatures at St. John's Harbour were recorded in August of both years. In 1970, the surface readings at the two stations were 13.0 and 13.1 C. In contrast, the highest temperatures at Aquaforte Harbour were recorded in September, 1969 when the surface reading was 11.4 C.

During the spring and summer, the temperature of the bottom waters did not arise above 2 C, and usually was considerably lower. Such low temperatures can sometimes be associated with the stabilization of the water column and the possible establishment of the thermocline. Uniform temperatures throughout the water column were not observed until October at Station 1, St. John's Harbour, and until September at Aquaforte Harbour. However, at Station 2, St. John's Harbour a great increase in bottom temperatures occurred as early as July. It was also observed that the waters of St. John's Harbour tended to warm up and cool off more quickly than those of Aquaforte Harbour.

A thermocline was established at Station 1, St. John's Harbour in July, 1970 between 11 and 14m (Figure 9). At Station 2, there was no stabilization of the water column. At Aquaforte Harbour, the thermocline occurred in August, 1969 between 15 and 19m (Figure 9).

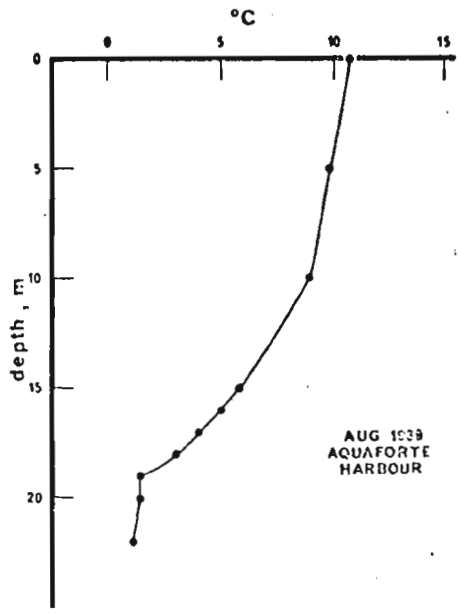
Oxygen

Ten monthly samples, collected in St. John's Harbour, from four depths, in the fall of 1969 and in the spring and summer of 1970, were analysed for oxygen content (Figures 10 and 11; Table IV).

Most significant in the samples taken at Station 1 was the decrease in oxygen concentrations at 22m. This occurred in all months except November and July, 1970, and was most prominent in August and October, 1969. A comparison of the 10 and 22m readings shows a decrease from 5.88 to 3.72 ml/l in August, 1969, and from 6.61 to 3.42 ml/l in October, 1969. The corresponding percentage oxygen saturations at 22m for the two months were 50 and 52%, respectively (Table IV).

The breakdown of the bottom oxygen minimum layer in November is of considerable importance because it suggests a flushing action in the harbour during the late fall. In fact, the bottom layer was supersaturated with oxygen (104%). The saturation values at 22m remained relatively high throughout

Figure 9. Temperature profiles showing thermoclines in August, 1969 at Aquaforte Harbour, and in July, 1970 at Station 1, St. John's Harbour.


°C
0
5
10
15
depth, m
AUG 1939
AQUAFORTE
HARBOUR

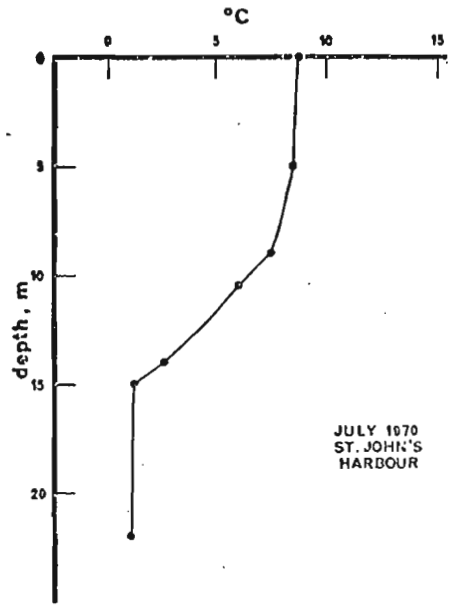

°C
0
5
10
15
depth, m
JULY 1970
ST. JOHN'S
HARBOUR

Figure 10. Oxygen profiles at the three sampling stations in 1969.

--- Station 1, St. John's Harbour

... Station 2, St. John's Harbour

___ Aquaforte Harbour

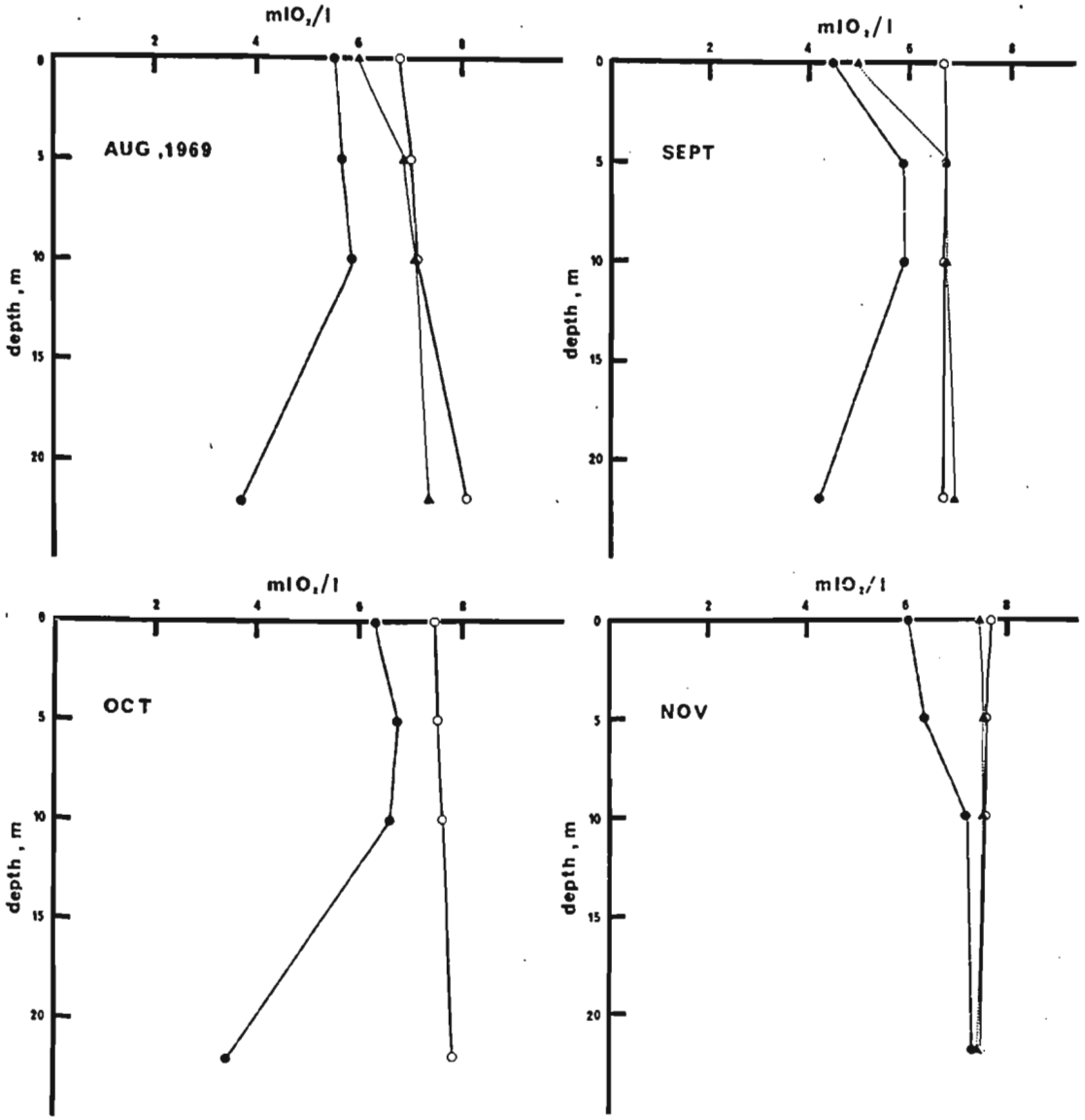

mlO,/l
AUG ,1969
SEPT
OCT
NOV
depth , m

Figure 11. Oxygen profiles at the three sampling stations in 1970.

--- Station 1, St. John's Harbour

... Station 2, St. John's Harbour

___ Aquaforte Harbour

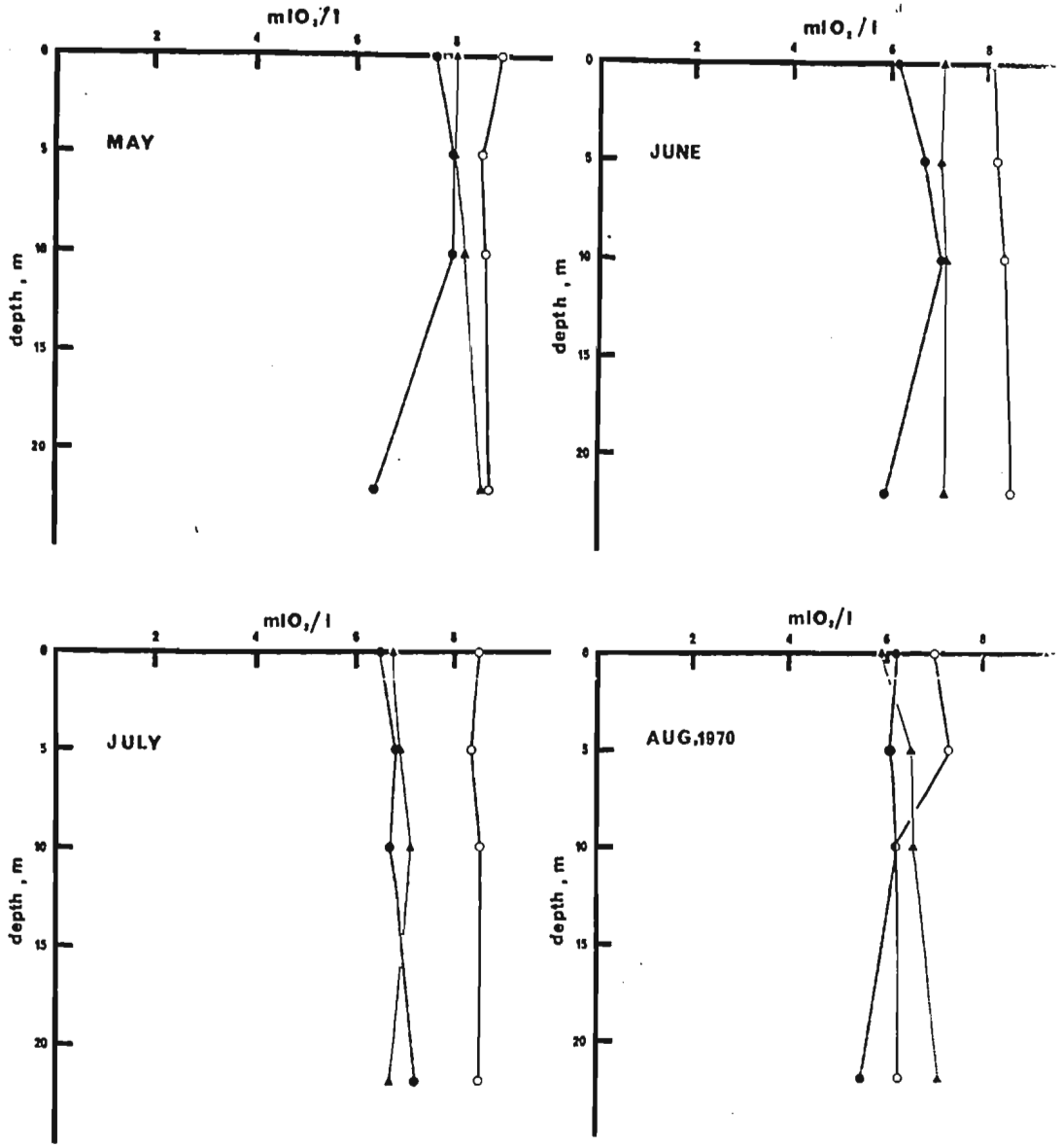

mlO₂/l
MAY
depth, m
mlO₂/l
JUNE
depth, m
mlO₂/l
JULY
depth, m
mlO₂/l
AUG,1970
depth, m

Table IV. Oxygen data in ml/l and percentage saturation [determined from Richards and Corwin's (1956) nomogram] for St. John's Harbour and Aquaforte Harbour.

m		1969 AUG	SEP	OCT	NOV	FEB	MAR	1970 MAY	JUN	JUL	AUG
Station 1, St. John's Harbour											
0	ml/l	5.55	4.49	6.31	6.05	7.75	7.65	7.60	6.17	6.50	6.18
	%	90.0	69.8	95.8	83.7	89.8	94.7	104.1	90.2	99.7	104.2
5	ml/l	5.68	5.90	6.76	6.40	8.02	8.29	7.95	6.71	6.82	6.09
	%	91.5	91.8	104.5	90.1	100.0	100.0*	105.6	95.5	104.3	98.4
10	ml/l	5.88	5.93	6.61	7.22	8.22	8.54	7.95	7.08	6.68	6.23
	%	91.0	86.2	102.0	101.8	102.8	103.5*	105.6	97.7	96.4	98.3
22	ml/l	3.72	4.23	3.42	7.37	7.90	7.93	6.39	5.94	7.20	5.53
	%	50.3	58.5	51.9	103.8	98.5	95.0*	80.7	76.7	92.1	72.7
Station 2, St. John's Harbour											
0	ml/l	6.01	5.01	-	7.49	8.40	8.23	8.03	7.11	6.76	5.89
	%	97.7	79.0	-	105.1	101.5	102.1	108.7	106.3	104.2	99.5
5	ml/l	6.89	6.74	-	7.57	8.34	8.75	7.98	7.05	6.88	6.52
	%	109.9	106.7	-	108.3	104.0	105.8*	105.0	104.4	104.7	104.3
10	ml/l	7.11	6.77	-	7.57	8.49	8.72	8.21	7.17	7.13	6.60
	%	112.5	105.8	-	108.5	105.9	105.7*	106.1	105.4	108.2	104.3
22	ml/l	7.38	6.94	-	7.46	8.43	8.75	8.58	7.17	6.88	7.14
	%	113.9	104.5	-	106.6	104.9	104.5*	109.3	103.3	99.1	104.5
Aquaforte Harbour											
0	ml/l	6.80	6.68	7.45	7.69	-	-	8.95	8.11	8.50	7.00
	%	109.9	109.0	112.7	108.3	-	-	117.3	112.2	114.4	114.2
5	ml/l	7.01	6.74	7.54	7.63	-	-	8.55	8.20	8.35	7.31
	%	110.9	110.0	113.9	108.7	-	-	111.5	107.9	111.6	117.3
10	ml/l	7.13	6.74	7.63	7.60	-	-	8.61	8.37	8.53	6.23
	%	110.9	110.0	114.9	108.3	-	-	111.1	108.0	111.1	97.2
22	ml/l	8.11	6.70	7.87	7.54	-	-	8.72	8.54	8.53	6.29
	%	104.5	108.6	116.6	106.5	-	-	111.4	107.6	107.3	94.2

* approximate values

February and March, not falling below 95%. However, by February a decrease from the 10m reading was again recorded at 22m, from 8.22 to 7.90 ml/l.

Only one month, August, 1970, showed a proportionately higher oxygen reading at the surface: 6.18 ml/l compared with 6.09 ml/l at 5m. In May and August, 1970, oxygen supersaturation values were observed at the surface.

Station 2 was sampled at the same time as Station 1, but no October samples were taken. Slight decreases in oxygen readings at 22m were found in November, 1969 and in February and July, 1970, indicating a layer of relative stagnancy near the bottom. However, these data are not as significant as those at Station 1; in two of these three months the water at 22m was supersaturated (107 and 105%), and in the other month almost completely saturated (99%).

Proportionately higher oxygen concentrations were found at the surface in February, May and June, 1970. However, these differences were not great when compared with the values for 5m: 8.40 ml/l compared with 8.34 ml/l in February, 8.03 ml/l and 7.98 ml/l, respectively in May, and 7.11 ml/l and 7.05 ml/l, respectively in June. Only May and June had slightly higher surface oxygen saturation values: 109% compared with 105% for

May, and 106% compared with 104% for June. Only in August and September, 1969 was the surface water not supersaturated with oxygen.

In Aquaforte Harbour, eight monthly samples were collected in the fall of 1969 and in the summer of 1970. In some months a regular pattern of oxygen concentrations (ml/l), showing a steady increase in oxygen witth depth, was discernable. Deviations from this pattern occurred when a slight oxygen minimum layer was noted at 22m in September and November, 1969, with a decrease of 0.04 ml/l in one case and of 0.06 ml/l in the other. In August, 1970 there was a decrease in oxygen at both 10 and 22m. When the percentage saturation of oxygen was calculated, low oxygen values occurred at both 10 and 22m at all months except October and May.

In May and July, 1970, oxygen concentrations at the surface were considerably higher than those at 5m: 8.95 ml/l compared with 8.55 ml/l in May, and 8.50 ml/l compared with 8.35 ml/l in July. With regard to the calculations of percentage saturations, May June and July showed the following higher concentrations at the surface: 117% compared with 112% for May, 112% compared with 108% for June, and 114% compared with 112% for July.

In comparing the three locations, there is generally a

progressive decrease in oxygen concentrations from Aquaforte Harbour to Station 2, St. John's Harbour, and to Station 1, St. John's Harbour. At 22m, the low oxygen concentrations are quite distinct at Station 1, while supersaturation seems more prevalent at Aquaforte. In addition, based on ml O_2/l, the Aquaforte values, which have a steady increase in oxygen with depth, appear to indicate the most stable water column.

The highest concentrations of oxygen in ml/l at Station 1 and 2 were in March, and at Aquaforte in May; the lowest concentrations for the three stations were August, 1969, August, 1970, and September, 1969/August, 1970, respectively. When the percentage saturation of oxygen was determined, the highest concentrations at Station 1, Station 2 and Aquaforte occurred in May, August, 1969 and October/August, 1970, respectively; the lowest concentrations were in September, August, 1970 and November/August, 1969, respectively. Thus the two methods of expressing oxygen concentrations did not give comparable results. Theoretically, the percentage saturation of oxygen would appear to give a better estimate of water conditions, since the solubility of oxygen in sea water is corrected for temperature.

Table V. Secchi disc depths and equivalent extinction coefficients in St. John's Harbour and Aquaforte Harbour.

	1969								1970			
	JUN	JUL	AUG	SEP	OCT	NOV	FEB	MAR	MAY	JUN	JUL	AUG
Station 1, St. John's Harbour												
depth (m)	-	4	3	2.5	5	1	2	4	5	3.5	3	3.5
extinction coefficient	-	.43	.57	.68	.34	1.70	.85	.43	.34	.49	.57	.49
Station 2, St. John's Harbour												
depth (m)	-	12	4.5	6	-	3	4	8	5	>19	6	5
extinction coefficient	-	.14	.38	.28	-	.57	.43	.21	.28	<.09	.28	.34
Aquaforte Harbour												
depth (m)	>19	9	-	-	8	8	-	-	13	19	>19	10
extinction coefficient	<.09	.19	-	-	.21	.21	-	-	.13	.09	<.09	.17

Secchi disc

Secchi disc readings were taken on most of the field trips. Both the depths at which the disc disappeared from view and the extinction coefficients were recorded (Table V). These data show that the water at Station 1, St. John's Harbour tended, throughout the year, to be more turbid than at the other two stations. Aquaforte Harbour had the clearest water.

Comparisons indicated that the winter months, November and February, had the lowest disc readings at all stations.

During the summer, varied results occurred at the three locations. At Station 1, in 1969, the maximum turbidity recorded (2.5m) was in September; in 1970,maximum turbidity (3m) occurred in July. At Station 2, maximum turbidities were obtained in August of both years (4.5m, 1969; 5m, 1970). Aquaforte Harbour showed the greatest turbidity in July, 1969 (9m), and in August, 1970 (10m).

Phytoplankton

Table VI gives a list of 85 species and 4 unidentified categories (μ-cells, flagellates, naviculoids and gymnodinians) from seven algal groups. Of the species, there were 9 Chlorophyceae, 1 Xanthophyceae, 45 Bacillariophyceae, 2 Chrysophyceae, 3 Euglenophyceae, 23 Dinophyceae and 2 Cryptophyceae. The table also provides the range of volume of the individual species and categories.

Table VII is a list of the major species giving the number of cells per litre at the four sampling depths, 0, 5, 10 and 22m, together with the volume or biomass under a surface area of 1 dm^2 at each location throughout the study.

a. Monthly Comparison of the Total Phytoplankton Biomasses

The most striking observation among the stations studied was the large phytoplankton biomass found in the central basin (Station 1) of St. John's Harbour during July of both years (Figure 12 and Appendix I). In 1969, this biomass was approximately five times that in either the Narrows (Station 2, St. John's Harbour) or Aquaforte Harbour. In 1970, for the same period, it was ten times that found at Station 2, and twenty times that found at Aquaforte Harbour. In August, 1969, Station 1 still had the greatest biomass

Table VI. List of species identified and their volumes.

SPECIES	VOLUME (μ^3)
CHLOROPHYTA	
CHLOROPHYCEAE	
Arthrodesmus incus (Debrébisson) Hassall	1,100-1,500
Carteria (?) sp. Diesing	50-60
Cosmarium sp. Corda	3,000-4,000
Euastrum sp. Ehrenberg	8,000
green flagellate "A"	150-300
green flagellate "B"	40-90
μ-cells	30-60
Netrium digitus (Ehrenberg) Itzigsohn and Rothe	47,000
Pediastrum sp. Meyen	4,000-13,000
Pyramimonas sp. Schmarda	100-200
Spirogyra sp. Link	70,000-90,000
Staurastrum sp. Meyen	8,000-47,000
CHRYSOPHYTA	
XANTHOPHYCEAE	
Halosphaera viridis Schmitz	100,000-6,700,000
BACILLARIOPHYCEAE	
Achnanthes sp. Bory	54,000-165,000
Amphiprora sp. Ehrenberg	54,000-203,000
Amphora sp. Ehrenberg	8,000-137,000
Asterionella formosa Hassall	500-800
Campylodiscus sp. Ehrenberg	23,000-45,000
Chaetoceros atlanticus Cleve	5,900-18,800

(Cont'd)

TABLE VI (Cont'd)

SPECIES	VOLUME (μ^3)
Chaetoceros concavicornis Mangin	4,700-18,800
Chaetoceros debilis Cleve	1,100-2,100
Chaetoceros decipiens Cleve	14,000-27,000
Chaetoceros gracilis Schütt	20
Chaetoceros septentrionalis Oestrup	600-800
Chaetoceros socialis Lauder	130-140
Chaetoceros sp. Ehrenberg	400-1,500
Cocconeis sp. Ehrenberg	500-2,000
Coscinodiscus centralis Ehrenberg	1,300,000-4,700,000
Coscinodiscus radiatus Ehrenberg	10,000-57,000
Coscinosira polychorda Gran	4,000
Eucampia greenlandica Cleve	21,000-54,000
Eucampia zodiacus Ehrenberg	14,000-23,000
Fragilaria crotonensis Kitton	600
Fragilaria islandica Grunow	900-1,800
Grammatophora serpentina Kützing	2,400-4,500
Leptocylindrus danicus Cleve	2,300-4,900
Licmophora sp. Agardh	1,000-3,000
Melosira moniliformis (O.F. Müller) Agardh	10,000-14,000
*Unidentified naviculoids	400-50,000
Nitzschia closterium Ehrenberg	20-50
Nitzschia delicatissima Cleve	130-250
Nitzschia reversa W. Smith	1,600-4,000
Nitzschia seriata Cleve	900-1,500
Pinnularia sp. Ehrenberg	39,000
Pleurosigma sp. "A" W. Smith	12,000-30,000
Pleurosigma sp. "B" W. Smith	200,000-600,000

TABLE VI (Cont'd)

SPECIES	VOLUME (μ^3)
Rhizosolenia alata f. gracillima Cleve	8,000
Rhizosolenia fragilissima Bergon	41,000-59,000
Rhizosolenia hebetata (Bailey) Gran f. semispina (Hensen) Gran	6,000-42,000
Rhizosolenia shrubsolei Cleve	70,000-270,000
Rhabdonema sp. Kützing	32,000-41,000
Surirella sp. Turpin	6,000-41,000
Synedra ulna (Nitzsch) Ehrenberg	7,000-11,000
Tabellaria fenestrata (Lyngbye) Kützing	1,000-4,000
Tabellaria flocculosa (Rothe) Kützing	7,000-20,000
Thalassiosira condensata (?) (Cleve) Gran	25,000-68,000
Thalassiosira nordenskiöldii Cleve	6,000-7,000
Thalassiosira sp. Cleve	5,000-25,000
Thalassiothrix longissima Cleve & Grunow	7,000-16,000
CHRYSOPHYCEAE	
Dinobryon sp Ehrenberg	80
Distephanus speculum (Ehrenberg) Haeckel	2,000-3,900
EUGLENOPHYTA	
EUGLENOPHYCEAE	
Euglena sp. "A" Ehrenberg	400-700
Euglena sp. "B" Ehrenberg	100-120
Phacus sp. Dujardin	8,000-15,000
PYRROPHYTA	
DINOPHYCEAE	
Amphidinium sp. Claparède & Lachmann	700-1,200

TABLE VI (Cont'd)

SPECIES	VOLUME (μ^3)
Ceratium arcticum (Ehrenberg) Cleve	90,000-126,000
Ceratium fusus (Ehrehberg) Claparède & Lachmann	61,000-98,000
Ceratium lineatum Ehrenberg	26,000-195,000
Ceratium longipes (Bailey) Gran	76,000-137,000
Dinophysis ellipsoides Kofoid	30,000
Dinophysis norvegica Claparède & Lachmann	80,000-151,000
Glenodinium sp. (Ehrenberg) Stein	1,300-3,500
Gonyaulax diacantha (Meunier) Schiller	2,400-3,900
Gymnodinium filum Lebour	2,700
Gymnodinium pygmaeum Lebour	290-360
Gymnodinium simplex Lohmann	60-90
*Unidentified gymnodinians	100-18,000
Gyrodinium glaucum (?) Lebour	700-1,000
Gyrodinium spirale Bergh	4,000-21,000
Oxyrrhis marina Dujardin	140-200
Oxytoxum sp. Stein	1,400
Peridinium depressum Bailey	600,000-1,400,000
Peridinium ovatum (?) (Pouchet) Schütt	24,000-46,000
Peridinium pellicidium (?) (Bergh) Schütt	100,000-180,000
Peridinium sp. Ehrenberg	36,000-50,000
Phalacroma rotundatum (Claparède & Lachmann) Jörgensen	30,000-80,000
Polykrikos sp. Bütschli	3,500
Unidentified Dinophyceae	89,000
CRYPTOPHYCEAE	
Rhodomonas (?) sp. Karsten	70-120

TABLE VI (Cont'd)

SPECIES	VOLUME (μ^3)
Unidentified Cryptophyceae	20-40

* Five groups of naviculoids ("A" to "E") and eight groups of gymnodinians ("A" to "H") were identified according to shape and size to ensure a more accurate estimate of the biomass.

Table VII. Number of cells per liter at the four sampling depths, and the volume or biomass ($\mu^3.10^6$) under a surface area of 1 dm^2 for some major species.

		m	µ-cells 1	2	3	Asterionella formosa 1	2	3	Chaetoceros debilis 1	2	3
		0	106542	11773	1285						15
J	N/L	5	132009	3950	1263						
U		10	60540	45459	1184						
L		22	98650	77078	1799						110
	VOL		1138	422	14						12
		0	347778	10260	300729						
A	N/L	5	16573	4735	27801						
U		10	361117	47780	274332	19					
G		22	458415	11609	64220						
	VOL		4944	247	1374	.83					
		0	1263360	892164	149052		67				
S	N/L	5	422073	53411	228081	176	249				
E		10	244631	140309	343484		238				
P		22	172787	61241	238655		426				
	VOL		4025	1988	3167	6.87	44.55				
		0	204978		15942						
O	N/L	5	33551		10060						
C		10	31570		15523						
T		22	819131		13091			10			
	VOL		2932		174			.49			
		0	359268	92643	377946		253				
N	N/L	5	329023	177671	147213	21	844				
O		10	243411	175133	84013	15	928				
V		22	166833	196714	118584	10	973		2		
	VOL		2919	1553	926	1.97	131.91		10		
		0	609867	286608	26395			9	34	125	99
M	N/L	5	237697	275228	30354				158	232	95
A		10	250989	163982	25656		17	9	308	72	405
Y		22	254899	21335	13075				78	53	2092
	VOL		3571	1880	278		1.05	.80	616	244	2237
		0	917893	33427	9196		39				
J	N/L	5	225644	21412	31894	27	26				
U		10	188439	24379	7955	36	34				
N		22	97226	84686	15441		9	13			4
	VOL		3141	426	158	2.78	4.45	.63			3
		0	213414	196052	37085						
J	N/L	5	142257	83507	64008						12
U		10	257503	122505	36593						2
L		22	117056	160590	23475				21		20
	VOL		2316	1369	398				11		26
		0	1539502	1566059	306472						
A	N/L	5	735357	835688	265749						
U		10	521598	266760	196311						
G		22	427428	228940	212015						
	VOL		8133	5545	2316						

Cont'd

TABLE VII (Cont'd)

		Chaetoceros decipiens			Chaetoceros socialis			Leptocylindrus danicus			Navicula spp. "B"		
	m	1	2	3	1	2	3	1	2	3	1	2	3
JUL	0											2	
	5			22									
	10										33	88	10
	22			59								62	
	VOL			105							10	26	6
AUG	0										78		
	5												
	10										38		23
	22										115		210
	VOL										38		28
SEP	0										183		66
	5			2							17	4	46
	10										31	15	102
	22										122	24	20
	VOL			5							68	25	74
OCT	0												38
	5										8		37
	10										10		37
	22										8		46
	VOL										8		95
NOV	0										20	8	50
	5										10	4	36
	10										30	6	15
	22	8									8		36
	VOL	14									28	2	68
MAY	0	9	46	22	4555	8556	734	51	21	160	72	71	26
	5	30	36	35	12259	3361	1890	219	196	95	61	18	17
	10	77	55	66	13337	2343	46679	96	77	70	45	13	33
	22	137	53	51	79647	3241			84		13	9	188
	VOL	573	548	918	2677	446	875	191	238	77	43	19	132
JUN	0								6		111	34	69
	5							13			139	17	125
	10									148	102	34	17
	22			4				53		229	11	53	73
	VOL			22				44	3	334	88	33	102
JUL	0			2						1261	24	45	121
	5			26					27	646	16	27	47
	10			24					5	517	34	5	53
	22	26	3	20				636	48	515	58	53	95
	VOL	87	8	186				441	59	998	36	26	115
AUG	0										70	177	10
	5										59	60	
	10								45		79	18	5
	22							6			79	5	124
	VOL							1	14		74	40	60

TABLE VII (Cont'd)

		m	Navicula spp. "D" 1	2	3	Nitzschia closterium 1	2	3	Nitzschia delicatissima 1	2	3
		0		264	865			10			
J	N/L	5		288	789			7			
U		10	79	156							
L		22			3935	10		191			
	VOL		1	27	292	.03		.53			
		0	1752	1263	190			10			
A	N/L	5	1184	1263	170						
U		10	1780	133	232		8				
G			1080	262	10	15		10			
	VOL		232	56	29	.04	.03	.05			
		0	2458	2233	1759			2	20	13	
S	N/L	5	4106	300	2643			8	17		
E		10	1612	990	832					11	
P		22	1650	2342	480					61	
	VOL		277	108	88			.02	.21	.39	
		0	1106		1908			2			
O	N/L	5	1356		3308						
C		10			3011						
T		22	599		2873						4
	VOL		89		890			.00			.04
		0	7360	5028	8600	40		4	120	2	50
N	N/L	5	3940	2578	5673	15	6	11	23	25	55
O		10	2993	2965	3849	17	4	11	15	42	8
V		22	4047	2340	4145	33	10	25	81	31	55
	VOL		503	291	375	.23	.02	.09	2.58	1.15	1.01
		0	4043	10982	660		8	9			
M	N/L	5	5387	5914	660		54	9			
A		10	5296	2603	675	13	9	22			
Y		22	996	945	9414	39	9	180			
	VOL		478	366	409	.15	.16	.72			
		0	15446	2585	1511			34	40	2566	
J	N/L	5	9737	263	2339			14	244	1100	
U		10	6018	1283	663				61	825	
N		22	1781	1479	1452	16	18	86		489	
	VOL		810	131	224	.04	.04	.32	2.89	34.32	
		0	2208	12190	2376			52			
J	N/L	5	1188	2284	1778		11	41		11	6
U		10	1041	819	743			44			
L		22	321	489	1105	5	32	140	37		
	VOL		121	245	208	.01	.09	.74	.35	.09	.05
		0	1711	5401	1074						
A	N/L	5	1512	3851	1286						
U		10	1011	958	471		4				
G		22	1304	596	9821			6			
	VOL		153	211	540		.01	.02			

TABLE VII (Cont'd)

		Nitzschia seriata			Distephanus speculum			Euglena sp. "A"		
	m	1	2	3	1	2	3	1	2	3
	0		17	208				1009387	20373	37500
J	5			1310			7	1427494	20471	51693
U N/L	10			160				79896	42770	8287
L	22	25	23	2973				16573	29710	4609
VOL		1.74	1.89	387.98			1.09	67022	3737	6305
	0							1037338	220187	560
A	5							378421	58401	4138
U N/L	10				5	8	10	30648	43718	1161
G	22				8		20	6669	44579	
VOL					3.55	1.64	7.54	20436	10089	175
	0						13	1405		
S	5					21	30	6287	106	
E N/L	10				30	15	43	645	264	43
P	22						860	132	1972	
VOL					9.04	5.64	111.59	224	99	2
	0							390		
O	5							10421		
C N/L	10						4	2762		
T	22							86		
VOL							1.05	524		
	0				20	6	12	640	2	
N	5				17	194	61		36	
O N/L	10				11	266	40		101	
V	22				8	108		8	82	
VOL					8.73	93.96	25.87	11	10	
	0	13	59						4	
M	5	18		4				120	18	
A N/L	10		85						13	
Y	22		75							
VOL		1.40	11.95	.23				4	1	
	0			43				4586	755	22
J	5	687		21				371414	4729	28
U N/L	10	61		169				13722	39006	
N	22	101	13	26				162	6587	
VOL		52.07	.89	20.61				13526	2701	1
	0			151				1372771	336752	4994
J	5			116				2440214	433593	7790
U N/L	10			186				162701	66645	203
L	22	126	13	163				4289	8483	27
VOL		8.63	.89	40.16				116054	24701	363
	0							22561	21189	1161
A	5							114626	72825	3137
U N/L	10							17797	8896	72
G	22							201	20	824
VOL								5326	3356	164

TABLE VII (Cont'd)

		Ceratium arcticum			Ceratium fusus			Ceratium longipes			Dinophysis ellipsoides		
		1	2	3	1	2	3	1	2	3	1	2	3
JUL	0		17	15		4			26			22	15
	N/L 5		15	5					10			5	7
	10		8	5					16		5	20	5
	22	5	16	5	5				8			4	
	VOL	30	284	153	22	7			245		13	82	35
AUG	0		5	60			10		5	40			
	N/L 5		15	30					5	30			
	10		20	57			4		39	30	10		
	22		19						4				
	VOL		333	773			43		379	575	26		
SEP	0			2			13			66			
	N/L 5		4	2		13	19	13	53	59			
	10	2		2		24	11	2	76	58			
	22					4	15		44	65			
	VOL	21	25	30		197	205	81	1159	1164			
OCT	0				11		18			9			
	N/L 5				33		44	10		11			
	10				10		44			15			
	22						40	4		10			
	VOL				266		790	56		239			
NOV	0		6	15		11	89		27	77			
	N/L 5	6	19	19	27	2	198	71	25	116			
	10	15	17	21	30	13	237	64	38	155			
	22	35	21	6	21	19	38	60	48	17			
	VOL	332	344	336	444	226	2673	1155	735	2134			
MAY	0		4					9	6				
	N/L 5					2		6		9			
	10		2	2		2		6	4				
	22		7	2				3					
	VOL		68	35		26		130	46	53			
JUN	0		8	15		3					16	96	
	N/L 5	3	13	3	3	9		3	2	3		56	
	10	12	21	2		4		4	21	7		34	
	22	16	22					3	9				
	VOL	197	365	81	13	72		75	260	79	12	243	
JUL	0		3	4					3	?			
	N/L 5		19	15					5			5	
	10	2	24	2		5		2	21	2		11	2
	22	11	16						8			3	
	VOL	86	446	108		32		18	271	30		41	5
AUG	0		14	98					3	43			
	N/L 5		153	63			3		69	42			
	10	3	159	105		2		3	45	18			
	22		59	209		2			137	11		15	
	VOL	23	2299	2628		22	91	24	1434	538		27	

TABLE VII (Cont'd)

		m	Dinophysis norvegica 1	2	3	Glenodinium sp. 1	2	3	Gymnodinium pygmaeum 1	2	3
		0		4	8	51929	1160	425		178	472
J	N/L	5			7	22984	1181	7			
U		10		12		153	604			244	158
L		22		5		237	156	29		475	2586
	VOL			153	44	5613	526	39		19	65
		0			10	870	22492	430			550
A	N/L	5			20	2368	5103	370			270
U		10		4	80	1161	1103	542	1393	352	1316
G		22		5	20	391	813	120	11935		390
	VOL			82	1345	609	2042	216	306	7	48
		0			13			130			716
S	N/L	5		4	8	34	72	258	385	65	1225
E		10		2	9	129	114	307	1354	67	1533
P		22			5	132	134	20	10954	335	400
	VOL			44	234	50	27	79	254	9	71
		0				130		237			68
O	N/L	5			2	998		68			203
C		10	5		7	158		134			67
T		22			4	471		447	770		128
	VOL		50		120	428		155	16		7
		0				280	4	33			
N	N/L	5			11	127	154	322	3177	322	709
O		10			17	651	84	449	7678	322	2695
V		22				757	253	453	4806	190	2461
	VOL				304	204	50	104	357	16	93
		0				26	29	198		511	990
M	N/L	5	6			36		22	371	807	1320
A		10				32	13	22	785	1432	3106
Y		22				33		9	7370	810	
	VOL		35			19	4	62	178	58	105
		0		28			96			1034	657
J	N/L	5	7	22		20	26	2552	406	2890	2126
U		10		29		16	25	199	18537	3593	1260
N		22		4		21	13	4	20239	1882	924
	VOL		44	530		10	14	346	950	168	85
		0					34	1056		858	1848
J	N/L	5		13			107	1422		326	2845
U		10		11		43	70	5671	130	2292	2836
L		22		13		68	64	23	24747	489	690
	VOL			278		21	34	1387	506	75	140
		0			15	7	41	2138	107		5674
A	N/L	5		5	29	20	230	284		502	
U		10			18	79	488	98	506	684	4083
G		22		2	6	214	405	243	12299	2385	1723
	VOL			44	473	55	168	216	265	65	176

TABLE VII (Cont'd)

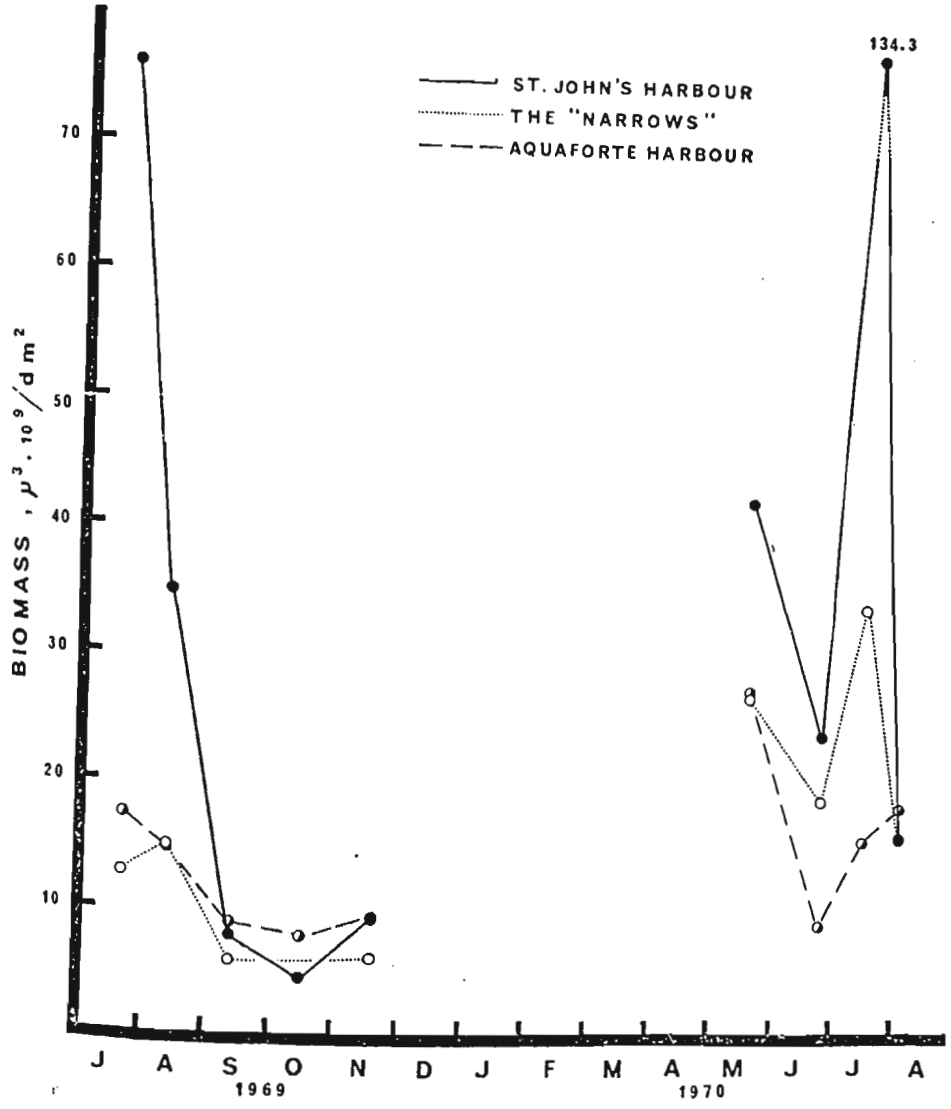
		m	Gymnodinium spp. "B" 1	2	3	Gyrodinium spirale 1	2	3	Peridinium depressum 1	2	3
		0	6787	264	786		52	479			15
J	N/L	5	7553				20	87			
U		10	1711	244	631	153	92	50			10
L		22	631	357	787	30	54	206		4	10
	VOL		399	24	76	140	149	423		182	1316
		0	149847		1400		5				10
A	N/L	5	142845		200					5	
U		10	1626	1720	1393	8	12			4	11
G		22	1989	2090	850	46		330	4	8	
	VOL		7100	85	84	33	13	254	185	842	944
		0			2278			130			2
S	N/L	5	2181	709	2901	50	114	129	4	2	6
E		10	967	1122	1883	20	140			2	9
P		22	2442	1204		61	133	200		2	
	VOL		125	73	112	74	51	278	145	283	766
		0									7
O	N/L	5			68				2		13
C		10	158		335						7
T		22	385								4
	VOL		22		15				69		929
		0			1202		30	21		2	
N	N/L	5	1140	451	580	71	78	248			4
O		10	1692	580	385	119	118	200			13
V		22	2150	316		184	25	17	2	2	
	VOL		284	46	48	106	182	271	407	154	715
		0			31	38	171	349	15	15	54
M	N/L	5	929		122	115	142	320	33	53	43
A		10	785		338	584	550	416	138	60	44
Y		22	61		1046	776	411	184	59	38	
	VOL		71		46	767	1702	1200	23785	14309	8286
		0	61		197		175	69	8	28	4
J	N/L	5	4260	263	425	27	202	550	7	28	17
U		10		122		40	345	365	20	29	13
N		22	486	672		711	115	95	5	4	6
	VOL		148	27	12	353	570	846	2442	4545	2356
		0	242254	35712			23	173			13
J	N/L	5	263079	27733	61		32	460			20
U		10	4165	6386	810		43	562		8	24
L		22	4017	2284	276	184	102	289	3		2
	VOL		11962	4231	41	104	134	1185	150	566	3485
		0		415	4754	7		181			8
A	N/L	5	1059		15748		38	248			13
U		10	607	411	3769	14	85	123	3		8
G		22		298		6	149	197		17	
	VOL		63	26	568	16	203	503	215	860	1291

Figure 12. Comparison of the total biomasses at the three sampling stations.

____ Station 1, St. John's Harbour

... Station 2, St. John's Harbour

--- Aquaforte Harbour


134.3
ST. JOHN'S HARBOUR
THE "NARROWS"
AQUAFORTE HARBOUR
BIOMASS , $\mu^3 . 10^9 / d\,m^2$
70
60
50
40
30
20
10
J A S O N D J F M A M J J A
1969
1970

even though it was half of the previous month's value.

During the fall of 1969 the biomasses decreased considerably, and were approximately equal at all three stations, with Aquaforte Harbour having a slightly larger biomass from September to November. During these months the lowest biomass was recorded at Sation 2. In the following May Station 1, St. John's Harbour had again attained the greatest biomass. The biomasses of the three stations decreased from May to June, but rose again in July, when an even greater biomass was observed for Station 1 than at the same time in the previous year. During the summer of 1970 the second highest biomass was recorded at Station 2. During July the biomass at Aquaforte Harbour continued to increase, and attained a somewhat greater value than at either of the St. John's Harbour stations, which had decreased drastically during this period.

b. Distribution of the Dominant Algal Groups

An analysis of the data from the three stations showed that different groups of phytoplankton dominated the population at different times of the year (Table VIII). The greatest similarity occurred between the two St. John's Harbour stations. At Station 1, the Euglenophyceae were the most abundant group predominating in July and August, 1969 and in June and July, 1970. In particular, in July of both years, they comprised 88 and 86% of the total biomass. The Chlorophyceae were the

Table VIII. Percentage biomass of the various algal groups within the total phytoplankton population.

Station 1, St. John's Harbour

ALGAL GROUP	1969 JUL	AUG	SEP	OCT	NOV	1970 MAY	JUN	JUL	AUG
Chlorophyceae	2.16	15 19	55.64	61.55	35.21	8.66	13.33	1.86	52.88
Xanthophyceae	.11		2.22	-	6.51	-	-	-	-
Bacillariophyceae	.20	1.03	13.07	2.82	7.83	28.49	5.04	1.37	5.04
Chrysophyceae	-	.01	.11	-	.09	-	1.53	.00	-
Euglenophyceae	88.25	58.48	4.63	10.98	2.92	.46	57.63	86.41	33.86
Dinophyceae	9.20	25.12	21.50	24.42	46.85	62.35	21.84	10.09	7.80
Cryptophyceae	.10	.17	2.82	.23	.59	.04	.65	.27	.43

Station 2, St. John's Harbour

Chlorophyceae	3.78	4.48	36.66	-	28.37	7.09	2.62	4.30	36.57
Xanthophyceae	23.92	-	-	-	12.50	-	27.26	-	-
Bacillariophyceae	16.77	.65	3.54	-	8.25	26.85	3.31	1.37	2.54
Chrysophyceae	-	.01	.09	-	1.46	-	6.42	-	-
Euglenophyceae	30.91	67.13	3.47	-	7.17	.45	15.81	72.96	22.09
Dinophyceae	24.00	26.27	48.11	-	31.18	65.33	42.85	19.24	35.75
Cryptophyceae	.62	1.45	8.13	-	11.07	.28	1.73	2.13	3.05

Aquaforte Harbour

Chlorophyceae	.10	11.86	42.48	2.51	11.11	1.51	2.06	2.64	14.02
Xanthophyceae	1.60	27.28	3.25	-	-	4.10	19.01	6.47	29.31
Bacillariophyceae	45.68	23.64	5.23	24.12	9.27	55.12	18.31	38.90	3.75
Chrysophyceae	.01	.05	1.24	.01	.27	-	-	-	-
Euglenophyceae	36.30	1.22	.03	-	2.49	1.25	4.18	4.14	2.19
Dinophyceae	14.94	32.94	36.88	73.22	76.03	37.85	55.14	45.55	38.91
Cryptophyceae	1.40	3.01	10.89	.14	.84	.17	1.30	2.29	11.81

dominant group in early fall; in September and October they constituted over half of the biomass. In November and especially in May, the dominant group was the Dinophyceae.

At Station 2 the Dinophyceae dominated during most of the sampling period, but only in May (65%) did they constitute more than half the biomass. Next in importance were the Euglenophyceae, which had a summer distribution similar to that of Station 1, but with quantities somewhat reduced (67%, August 1969; 73%, July 1970). The Chlorophyceae represented a considerable portion of the biomass only in September, 1969 and August, 1970, but again the percentages were lower than those at Station 1 - 37% of the total population for both years.

At Aquaforte Harbour the Dinophyceae clearly dominated the population most of the year, especially in late fall when the percentages of the total biomass for October and November were 73 and 76%, respectively. In July, 1969 and May, 1970 the Bacillariophyceae comprised approximately half the biomass. Again in September, the Chlorophyceae were an important constituent of the phytoplankton population.

c. Comparison of the Distribution of the Algal Groups

Chlorophyceae

The distribution of the Chlorophyceae (Figure 13A)

Figure 13. Comparison of: A. Chlorophyceae and

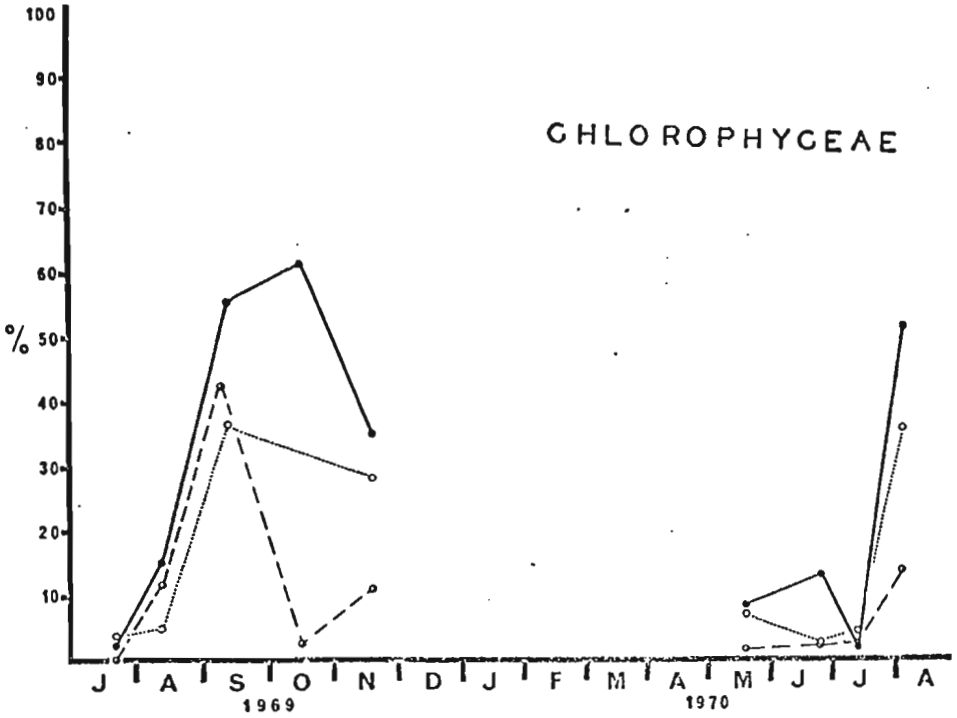
B. Xanthophyceae

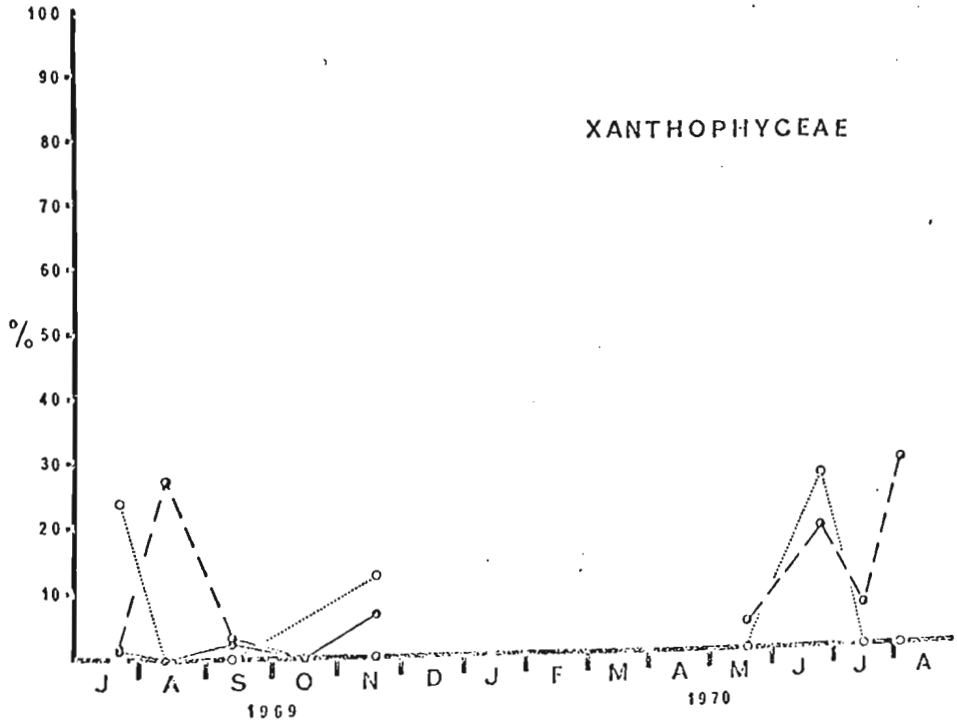
as percentages of the total biomass at the three stations.

___ Station 1, St. John's Harbour

... Station 2, St. John's Harbour

--- Aquaforte Harbour


CHLOROPHYCEAE
100
90
80
70
60
% 50
40
30
20
10
J A S O N D J F M A M J J A
1969
1970


XANTHOPHYCEAE
100
90
80
70
60
% 50
40
30
20
10
J A S O N D J F M A M J J A
1969
1970

was similar for the three stations. If the total phytoplankton population is considered, the summer population was proportionately low, but appeared to reach its peak in late summer or early fall at all stations, occurring earlier in 1970 than in 1969. In July of both years, Station 2, St. John's Harbour had the greatest concentration of green algae; otherwise, Station 1 had a proportionately greater biomass of this group of algae, especially in October when the percentage was twenty-five times that at Aquaforte Harbour. Usually, Station 2 had the next highest population in the remaining months.

Xanthophyceae

The Xanthophyceae, as represented by the species Halosphaera viridis (Figure 13B), was most abundant at Aquaforte Harbour. In August of both years it comprised approximately 28% of the total biomass. At St. John's Harbour, the pattern of distribution was different: the species was practically nonexistent at Station 1; at Station 2 its population was relatively high in July, 1969 and in June, 1970. This species was not observed in October.

The cell sizes determined for H. viridis agree with Brunel's (1962) literature survey on the variability of the species. In the present study, the diameter of the cells ranged from 60 to 240μ. Brunel's own dimensions from Baie des Chaleurs were relatively large (212 to 332μ). However, in the Labrador Sea, Holmes (1956) recorded much smaller cells (10 to 35μ).

Bacillariophyceae

The Bacillariophyceae (Figure 14A) exhibited a spring bloom in May at each station. The summer pattern of distribution varied considerably among the stations. At Aquaforte Harbour a second diatom increase occurred in July of both years, and in 1969, a smaller autumn bloom was evident in October. Generally,the Aquaforte diatom population exceeded that at at the other two stations. In St. John's Harbour the 1969 diatom population showed no discernable pattern of distribution A comparatively high concentration at Station 1 was noted in September. No autumn maximum was evident and by November the biomasses at the three stations were approximately equal. After the spring diatom bloom, the 1970 population decreased rapidly and remained low throughout the summer. Station 1 had a slightly larger biomass than Station 2.

Euglenophyceae

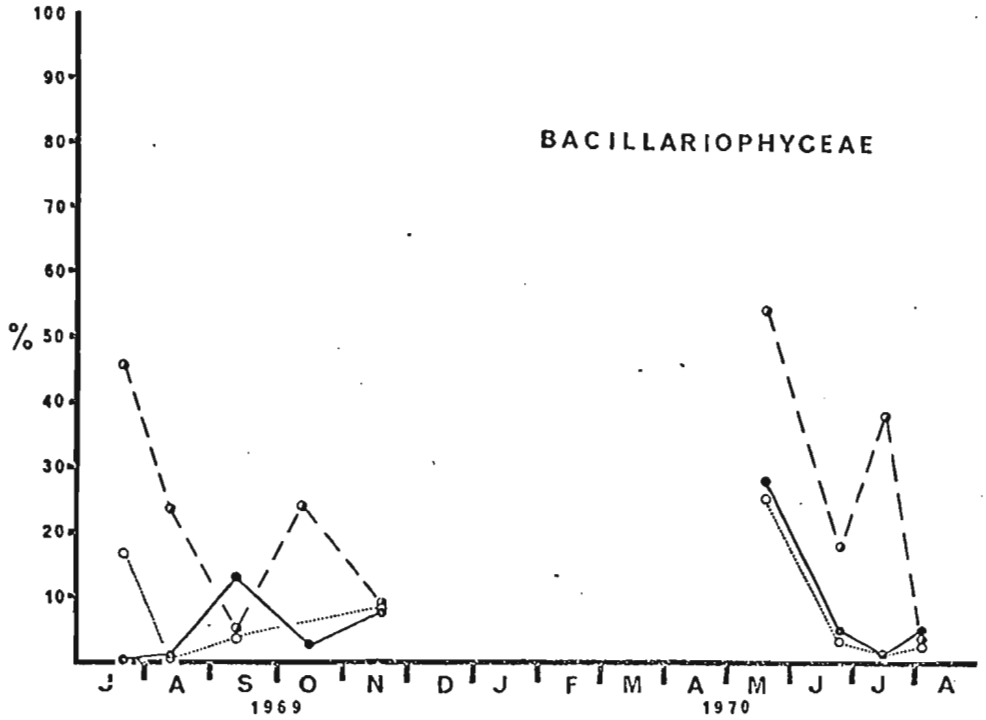
Most notable in the distribution of the Euglenophyceae (Figure 14B) was their dominance of the phytoplankton population in St. John's Harbour in July of bothyears; Station 1 had the larger biomass. After July, the euglenoids decreased rapidly in both years. In 1969, the fall population was relatively insignificant. In May the population was extremely low, but quickly increased to the July maximum. The euglenoids at Aquaforte Harbour were of little importance; they were virtually nonexistent in September and October. In July and August, 1970 they existed in concentrations which were 27 and 17 times, respectively, less than those at Station 1. However,

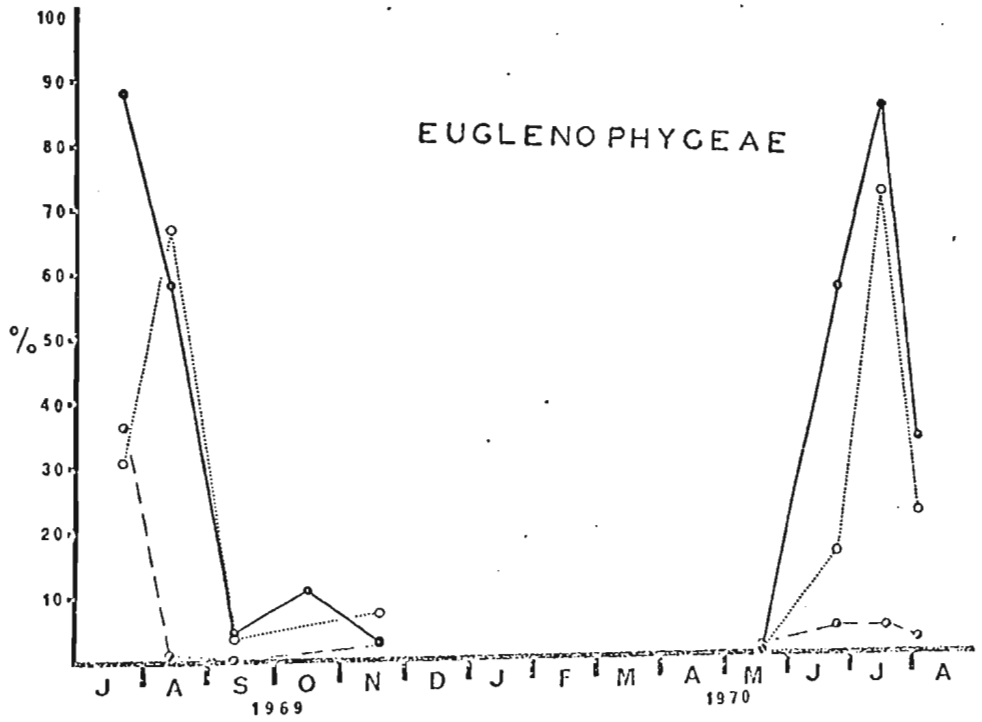
Figure 14. Comparison of: A. Bacillariophyceae and
B. Euglenophyceae
as percentages of the total biomass at the three stations.

___ Station 1, St. John's Harbour

... Station 2, St. John's Harbour

--- Aquaforte Harbour


BACILLARIOPHYCEAE
100
90
80
70
60
%
50
40
30
20
10
J A S O N D J F M A M J J A
1969
1970


EUGLENOPHYCEAE
100
90
80
70
60
%
50
40
30
20
10
J A S O N D J F M A M J J A
1969
1970

in May, the euglenoids at Aquaforte Harbour did outnumber those at St. John's Harbour.

Dinophyceae

The Dinophyceae (Figure 15) did not have a consistent distribution pattern, probably owing to the varied composition of the group, i.e. the armoured and unarmoured species. At Station 1, St. John's Harbour, the 1969 population rose during the summer to reach a maximum in November. By May of the following year, the concentrations were even higher, after which a decrease throughout the summer was noted. At Station 2 the highest percentages occurred in September. A spring maximum was followed by a sudden decrease as at Station 1. Nevertheless, the dinoflagellate population increased again in August. At Aquaforte Harbour the Dinophyceae exhibited two peaks: the larger one occurred in November and a slightly smaller one in June, 1970. In most months the largest populations of dinoflagellates were present at Aquaforte Harbour, although the percentages of this group of phytoplankton were consistently large at all the stations sampled.

Cryptophyceae

The Cryptophyceae were never a dominant group of the phytoplankton population, hence, total biomasses, instead of the percentage composition of the total population, were plotted in Figure 16. They were generally most abundant at Aquaforte Harbour, and least abundant at Station 1, St. John's

Figure 15. Comparison of the Dinophyceae as a percentage of the total biomass at the three stations.

___ Station 1, St. John's Harbour

... Station 2, St. John's Harbour

--- Aquaforte Harbour

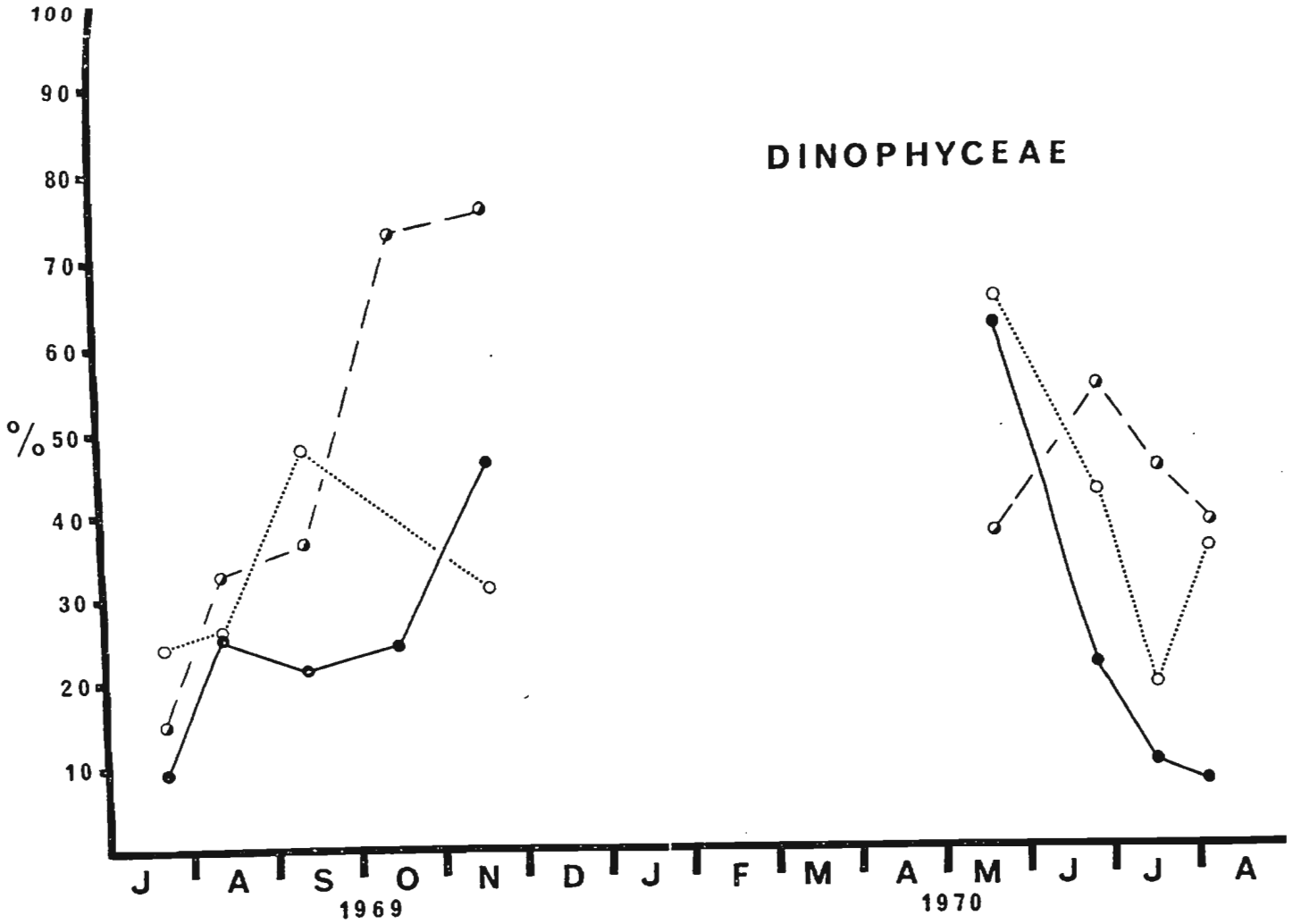
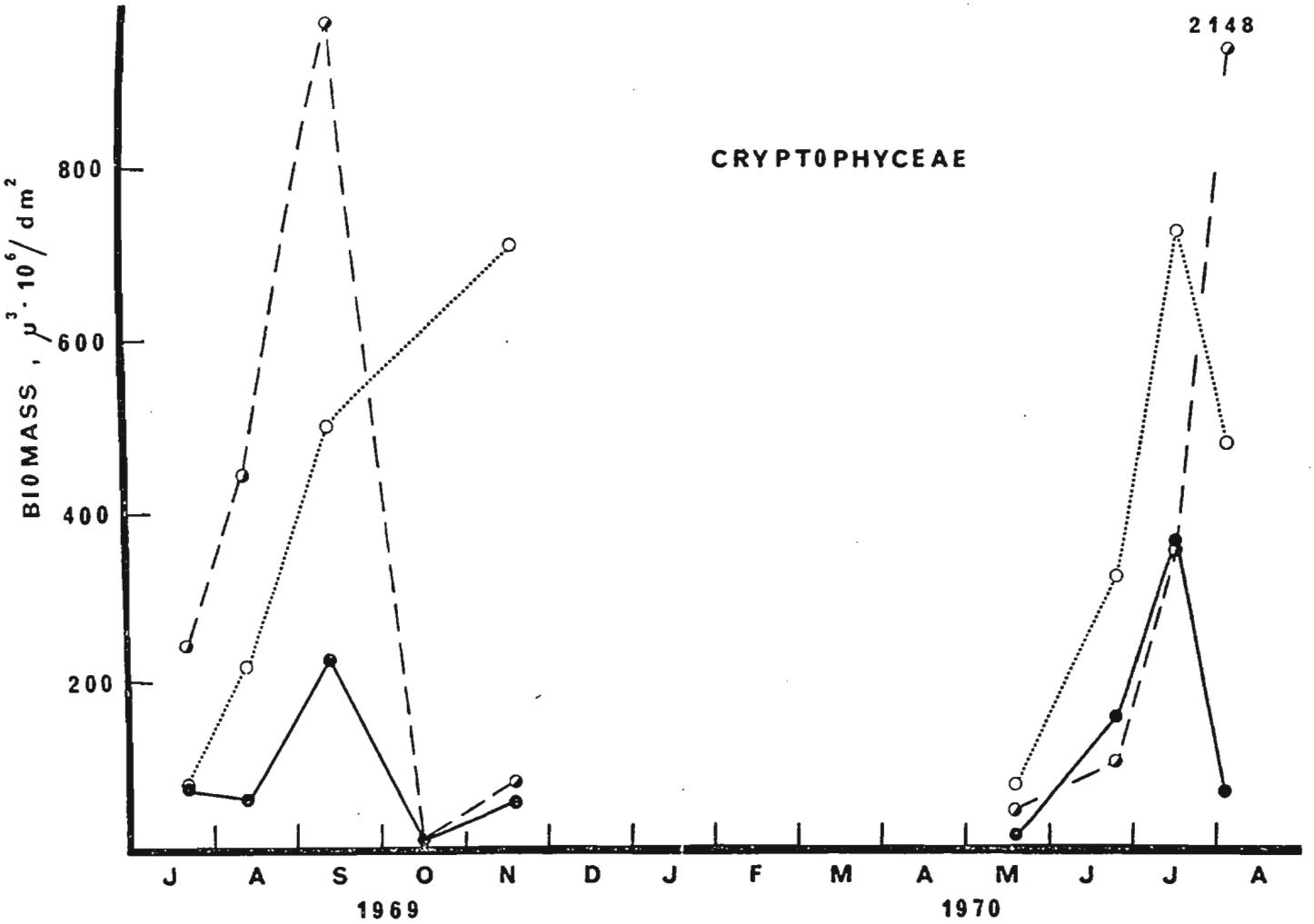

DINOPHYCEAE
100
90
80
70
60
% 50
40
30
20
10
J
A
S
O
N
D
J
F
M
A
M
J
J
A
1969
1970

Figure 16. Comparison of the biomasses of the Cryptophyceae at the three stations.

___ Station 1, St. John's Harbour

... Station 2, St. John's Harbour

--- Aquaforte Harbour


2148
CRYPTOPHYCEAE
BIOMASS , $\mu^3 \cdot 10^6 / dm^2$
800
600
400
200
J A S O N D J F M A M J J A
1969
1970

Harbour. In 1969, this group reached a population peak in September, except for Station 2, St. John's Harbour where the maximum population was attained in November. In 1970, both of the St. John's stations showed a gradual increase in biomass from May to a maximum in July, while the Aquaforte Harbour population continued to increase to August.

d. Comparison of the Distribution of the Major Species

Chlorophyceae

μ-cells

This group consisted of nonflagellated sph erical cells whose dimensions were less than 5μ and whose identification was impossible under the conditions of study. The assumption was made that these were Chlorophyceae, but they possibly included some Chrysophycean monads.

In all months the μ-cells dominated the Chlorophyceae at each of the stations. Generally, the highest concentrations were found in August, 1970. Comparing the three locations (Figure 17 and Table VII), this group was most abundant at Station 1, St. John's Harbour, where they comprised over half the total μ-cell population. In 1969, the remainder of this group was equally distributed between the other two stations. In 1970, the smallest population occurred at Aquaforte Harbour.

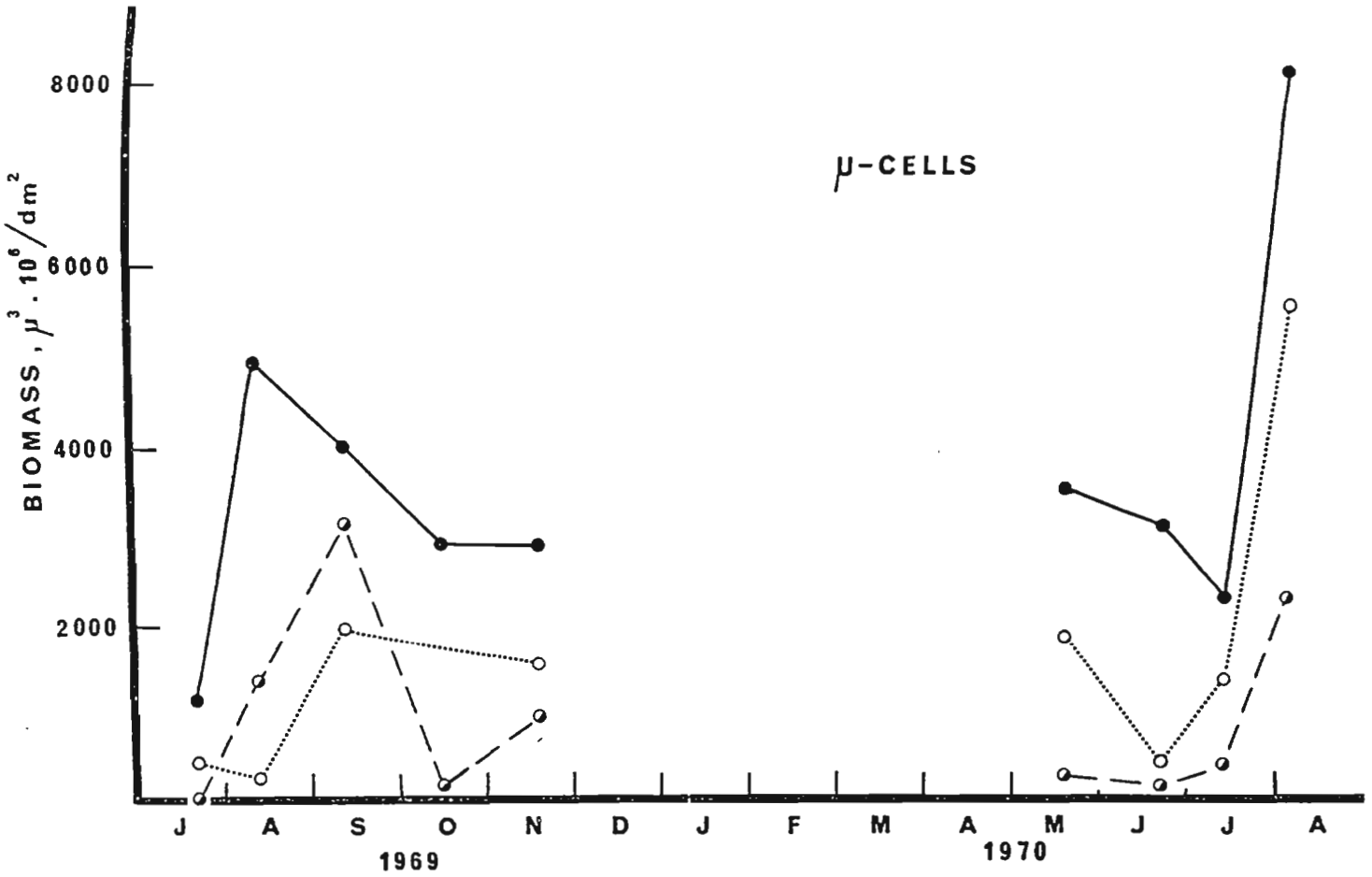
The μ-cells were most abundant in the surface samples,

Figure 17. Comparison of the biomasses of the μ-cells at the three stations.

___ Station 1, St. John's Harbour

... Station 2, St. John's Harbour

--- Aquaforte Harbour


μ-CELLS
BIOMASS, $\mu^3 \cdot 10^6/dm^2$
8000
6000
4000
2000
J
A
S
O
N
D
J
F
M
A
M
J
J
A
1969
1970

where they attained bloom concentrations according to Lackey's (1945) definition - 500 or more organisms/ ml. At Station 2, St. John's Harbour, these bloom populations were recorded only twice, but at Station 1, they occurred in five of the nine months sampled. In spite of their small volume (40 to 50μ^3), they were responsible for the Chlorophycean dominance of the total population at Station 1 in September and October, 1969 and August, 1970, when the corresponding percentages of the green algal population were 91, 99 and 97% (Appendix II). Although the concentrations of μ-cells did not reach bloom proportions at Aquaforte, their numbers were relatively high, and a peak occurred in September when they comprised 35% of the μ-cell population. Also at this time, the Chlorophyceae dominated the phytoplankton population.

The remaining Chlorophyceae included primarily two kinds of small flagellates and Carteria (?) sp., which showed no consistent pattern of distribution at any sampling station.

Bacillariophyceae

Navicula spp. "D"

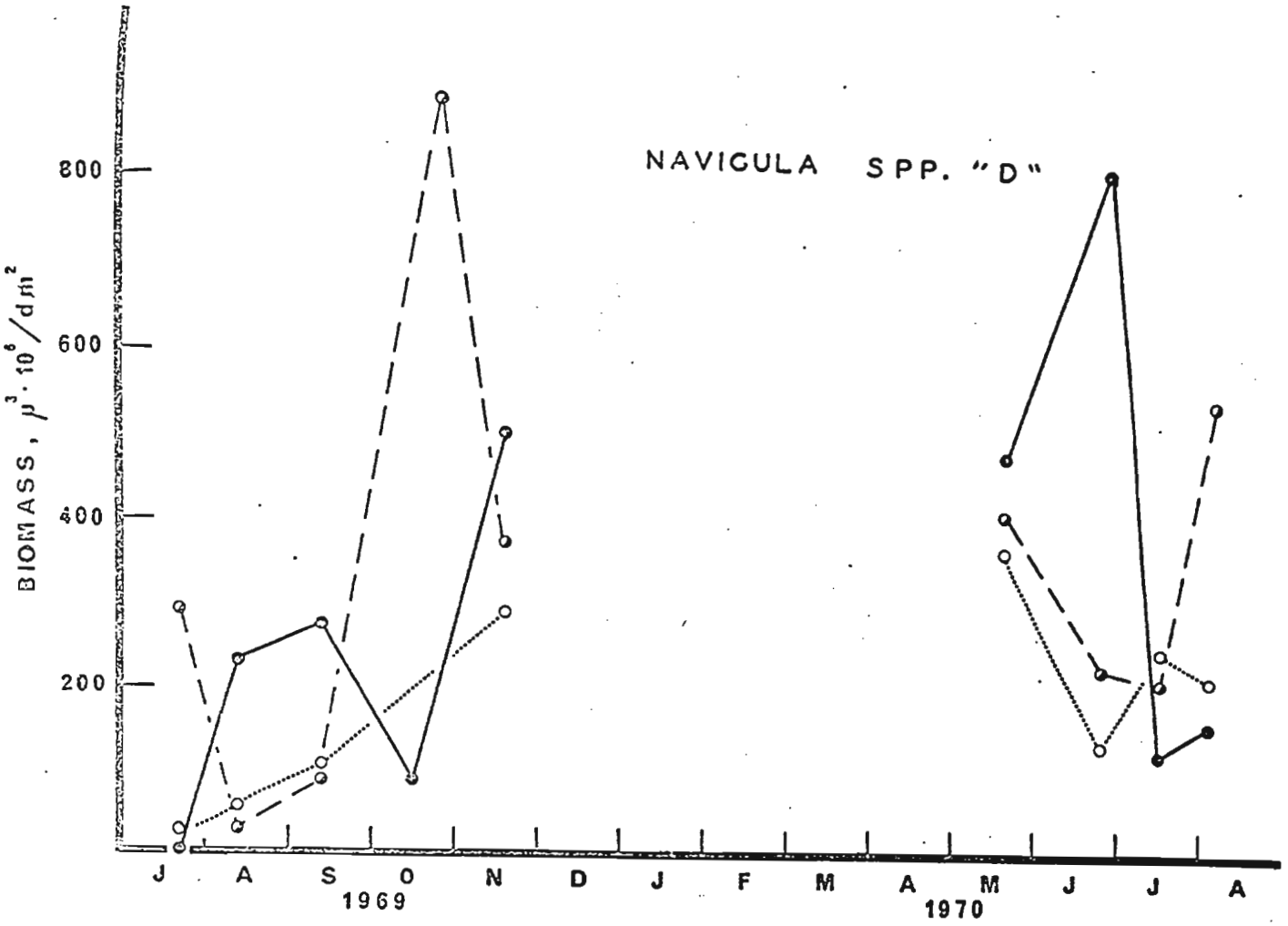
No Bacillariophyceae other than the small naviculoids (volume; 400 to 1,000μ^3), Navicula spp. "D" were consistently found in great abundance in all areas. The biomasses of these species (Figure 18 and Table VII) showed no consistent pattern in distribution, possibly because several species were involved.

Figure 18. Comparison of the biomasses of Navicula spp."D" at the three stations.

—— Station 1, St. John's Harbour

... Station 2, St. John's Harbour

--- Aquaforte Harbour


NAVICULA SPP. "D"
BIOMASS, $\mu^3 \cdot 10^6/dm^2$
800
600
400
200
J
A
S
O
N
D
J
F
M
A
M
J
J
A
1969
1970

On two occasions, July and October, 1969 at Aquaforte Harbour, these naviculoids comprised over 90% of the biomasses of these species for the three stations. During most months it was Station 1, St. John's Harbour which contained the greatest biomass. The species were most abundant in the surface sample, frequently more than twice the numbers observed at 5m.

Despite their persistent abundance, they were not the diatoms responsible for the occasions when the Bacillariophyceae dominated the phytoplankton, for at times when Nacivula spp. "D" were at peak production, e.g. October at Aquaforte Harbour, and June at Station 1, the diatoms, as a group, did not comprise a significant portion of the total biomass. However, these species were most important in St. John's Harbour; they were found to comprise over 65% of the diatoms in four months at Station 1 (Appendix II).

Navicula spp. "B"

Another group of naviculoids, Navicula spp. "B", were probably the second most abundant diatoms (Table VII). Though never comprising more than 10% of the diatoms in any one area (Appendix II), these medium-sized naviculoids (volume; 2,000 to 11,000μ^3) were persistent during all months. They were more prevalent at Aquaforte Harbour, except in August of both years, when their biomasses were greater at Station 1, St. John's Harbour.

Chaetoceros spp.

May was the month at all three locations, in which the Bacillariophyceae showed greatest abundance. At all stations this could be attributed to Chaetoceros spp. (Table VII), which appeared to dominate the spring bloom. At Station 1. St. John's Harbour they comprised 59% of the diatoms; at Station 2, 69%; and at Aquaforte Harbour, 82% (Appendix II). Unidentified Chaetoceros made up the largest portion of these percentages; they were usually long chains of cells with no apparent foramina (similar to Brunel's (1962) Chaetoceros sp. "B"), and with very short, straight, hairlike spines. They appeared to be concentrated at the 5m level. At Station 1 another species, Chaetoceros socialis, was prominent. This species was found in greatest numbers at 22m at Station 1 and at Aquaforte Harbour, while at Station 2, its greatest concentrations were at the surface. At Aquaforte Harbour the second most abundant species was Ch. debilis, which appeared to be concentrated at 22m. Other species which contributed less significantly to the populations were Ch. decipiens, Ch. concavicornis and Ch. atlanticus.

Euglenophyceae

Euglena sp "A"

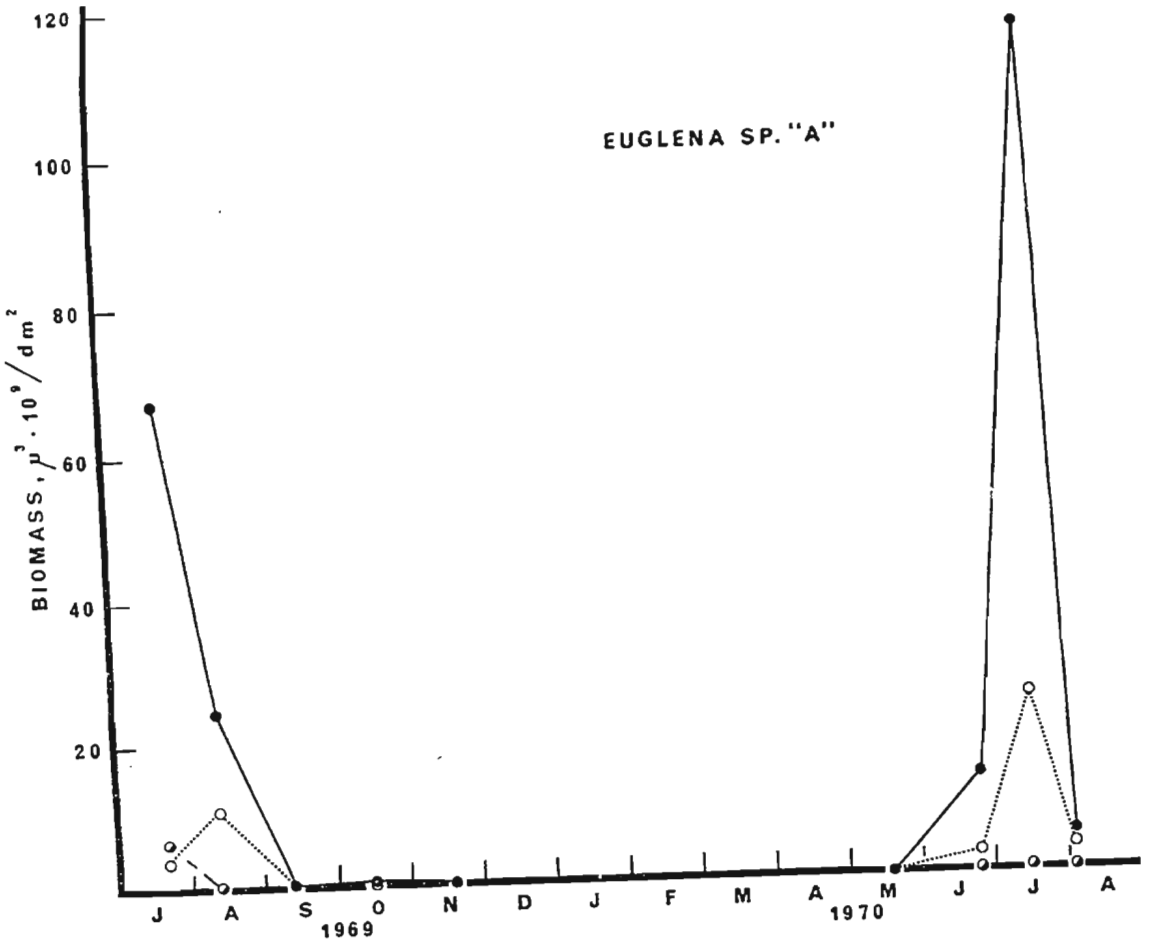
Of the Euglenophyceae, Euglena sp "A" was by far the most abundant species (Appendix II), and was responsible for the large phytoplankton populations in St. John's Harbour. In comparing the distribution ofthis species at the two stations in the harbour, Station 1 usually contained at least twice the

Figure 19. Comparison of the biomasses of Euglena sp "A" at the three stations.

____ Station 1, St. John's Harbour

... Station 2, St. John's Harbour

--- Aquaforte Harbour


EUGLENA SP. "A"
BIOMASS, $\mu^3 \cdot 10^9 / dm^2$
120
100
80
60
40
20
J
A
S
O
N
D
J
F
M
A
M
J
J
A
1969
1970

biomass as that at Station 2 (Figure 19). According to Lackey's (1945) definition of blooms (p.88), Euglena sp "A" reached bloom proportions at Station 1 in July of both years; the numbers observed in July ranged from 1,000 to 2,400 organisms/ml (Table VII). Furthermore, these numbers were concentrated in the upper 5m, where they were certainly responsible for the increase in turbidity as measured by the Secchi disc (Table V).

From September to November and continuing into May, Euglena sp. "A" declined drastically in importance at St. John's Harbour, while at Aquaforte Harbour it was absent during these months. Generally, at Aquaforte the species was of little significance even during the summer; the greatest numbers recorded were 52 organisms/ml in July, 1969.

Euglena sp "B"

In November and May another Euglena, Euglena sp "B" was recorded, primarily at both stations in St. John's Harbour (Table VII). The largest concentrations occurred at depths, 5 and 10m. It appeared to fill the euglenoid niche as the waters became colder. Since the volume of the two euglenas differed by a multiple of seven, it would appear that they represent two distinct species.

Phacus sp.

Another euglenoid, Phacus sp., was relatively abundant

throughout the year, with no distinct seasonal distribution (Table VII). It was recorded most often and in greatest abundance in the 22m sample, especially at the St. John's Harbour stations. Whether it tolerated lower temperatures or less light was not determined; this species may well be nonautotrophic.

Dinophyceae

Peridinium depressum

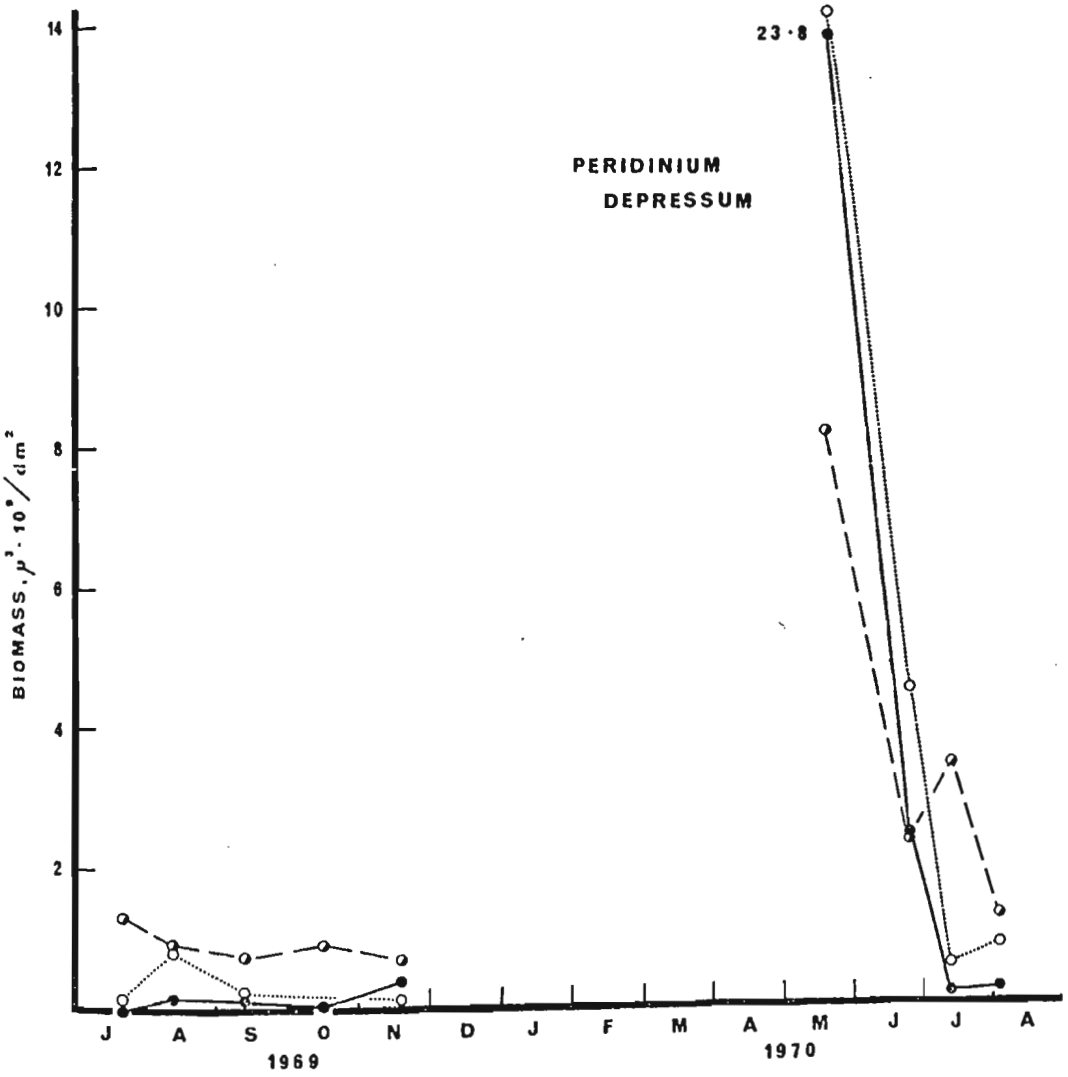
Of the Dinophyceae, the armoured dinoflagellate, Peridinium depressum had the greatest biomass on the average for all stations. Most significantly, the May population was extremely high (Figure 20 and Table VII), comprising 80, 81 and 90% of the dinophycean biomass in this month at Aquaforte Harbour, Station 2 and Station 1, St. John's Harbour, respectively (Appendix II). At both Station 1 and 2, this species was responsible for the dominance of the Dinophyceae during May (Table VIII). In June, 1970, percentages showed that P. depressum still dominated the Dinophyceae at Stations 1 and 2. During the other months, the biomasses of the species were considerably lower, and the distributional pattern was different in the two harbours. At Station 1 and 2 the biomasses decreased drastically in July, followed by a slight increase in August; this pattern occurred in 1969 and 1970. At Aquaforte a similar distributional pattern developed; the population decreased gradually to a minimum in August, followed in 1969 by a slight maximum in September.

Figure 20. Comparison of the biomasses of *Peridinium depressum* at the three stations.

____ Station 1, St. John's Harbour

... Station 2, St. John's Harbour

--- Aquaforte Harbour


PERIDINIUM
DEPRESSUM
23·8
BIOMASS, $\mu^3 \cdot 10^6 / dm^2$
14
12
10
8
6
4
2
J A S O N D J F M A M J J A
1969
1970

Comparing the data from the three sampling stations, P. depressum was usually most abundant at Aquaforte Harbour; the exceptions were in May and June, when it accounted for only 18 and 25%, respectively of the total P. depressum biomass for the three locations. At St. John's Harbour this species was found to be concentrated in the 10m sample; at Aquaforte Harbour the dinoflagellate was equally distributed at the intermediate depths.

Ceratium longipes

The armoured dinoflagellate with the second greatest biomass was Ceratium longipes (Figure 21 and Table VII). At Station 1, C. longipes was prevalent only in November at which time it comprised 26% of the dinophycean population (Appendix II), and was partially responsible for the dinophycean dominance. A different trend was evident at Station 2 and Aquaforte Harbour. In addition to the high November biomass, which was most pronounced at Aquaforte, another maximum was observed in September comprising 39 and 35% of the dinophycean population for the respective stations. On these occasions the Dinophyceae dominated the population at Station 2, but at Aquaforte only in November.

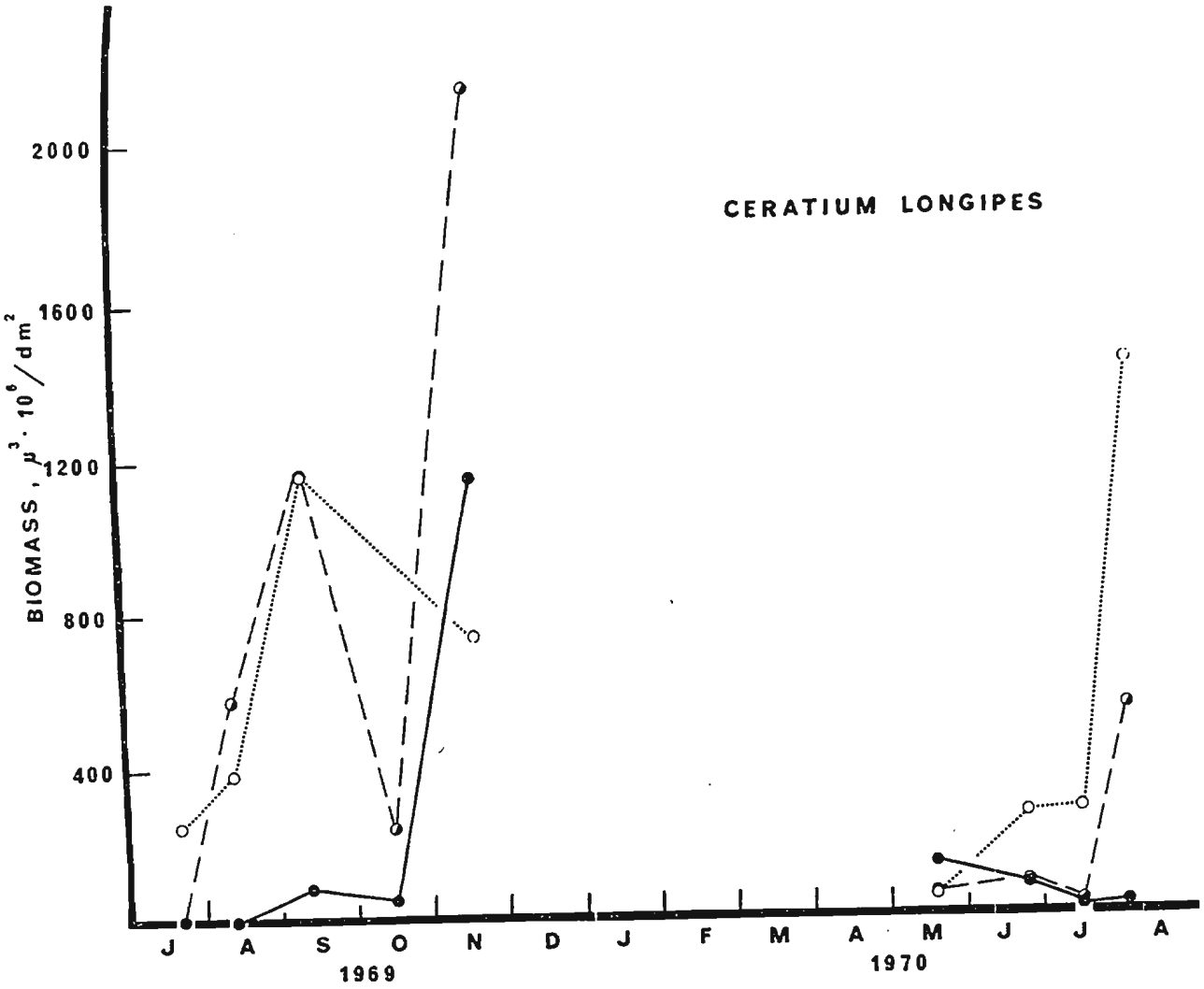
Except in May when C. longipes was concentrated at Station 1, the abundance of this species was fairly evenly distributed at the other two stations. At Aquaforte it was most abundant in late fall, while at Station 2 the greatest numbers occurred

Figure 21. Comparison of the biomasses of *Ceratium longipes* at the three stations.

——— Station 1, St. John's Harbour

... Station 2, St. John's Harbour

--- Aquaforte Harbour


CERATIUM LONGIPES
BIOMASS, $\mu^3 \cdot 10^6 / dm^2$
2000
1600
1200
800
400
J
A
S
O
N
D
J
F
M
A
M
J
J
A
1969
1970

in late summer.

At Station 1, C. longipes appeared to be concentrated in the upper 5m, while at Station 2 and at Aquaforte it was generally concentrated at the 10 and 22m levels.

Ceratium arcticum

The distribution pattern for Ceratium arcticum (Table VII) was considerably different from that for C. longipes. At Station 1, it did not represent a significant portion of the dinophycean population. On the other hand, at Station 2 and at Aquaforte, C. longipescomprised 41 and 37% of the dinoflagellate population in August, 1970 (Appendix II). However, only at Aquaforte was this maximum evident in the previous year, when it comprised only 16% of the dinophycean population.

The greatest biomass of the species was found at Station 2, followed by a slightly lower biomass at Aquaforte. C. arcticum appeared to be concentrated at the lower sampling depths.

Ceratium fusus

Ceratium fusus (Table VII) was almost exclusively confined to Aquaforte Harbour. This species appeared in the greatest abundance in November at all stations, having gradually increased in numbers from August onwards. During the spring and summer months it appeared to disappear completely from

Aquaforte, but remained in fairly low concentrations at Station 1. The number of cells per liter of C. fusus were comparable to those of the other ceratia. The species appeared to be concentrated at the intermediate sampling depths.

Ceratium lineatum

Ceratium lineatum was never present in any abundance at any station. Only in September did its numbers increase to any extent, and then primarily at Station 1 and 2, St. John's Harbour.

Glenodinium sp.

Another armoured dinoflagellate which had a biomass equivalent to Ceratium longipes was Glenodinium sp. (Table VII). Difficulty arises in describing the distribution pattern of this species of spherical shape, because it is vaguely defined taxonomically. No consistent pattern of distribution was evident. However, it comprised a considerable portion of the dinophycean population at St. John's Harbour: 80% in July, 1969 at Station 1, and 52% in August, 1969 at Station 2 (Appendix II). At Aquaforte Harbour it represented 20% of the dinoflagellate population in July, 1970. During the other months it was comparatively insignificant.

Except for the summer of 1969, it was found in greatest abundance at Aquaforte. No differences in abundance was discernable at the depths sampled.

Gymnodinium spp. "B"

Of the unarmoured Dinophyceae, Gymnodinium spp. "B" had the greatest biomass. This group was represented by medium-sized spherical cells, and possibly consisted of more than one species. Their late summer predominance in St. John's Harbour is shown in Figure 22 and Table VII. At Station 1, they represented 81% of the dinophycean biomass in August, 1969, and 88% in July, 1970 (Appendix II). Station 2 showed only the July, 1970 increase, at which time they comprised 65% of the dinophycean population. However, since these months were not marked by large dinoflagellate populations, these species were not considered to be an important component of the algal population. Only in August, 1970 did Gymnodinium spp. "B" become significant at Aquaforte Harbour, at which time they represented 86% of the total G. spp. "B" biomass of the three locations.

The vertical distribution is difficult to assess, but the species appeared to be concentrated near the surface when they occurred in large numbers.

Gyrodinium spirale

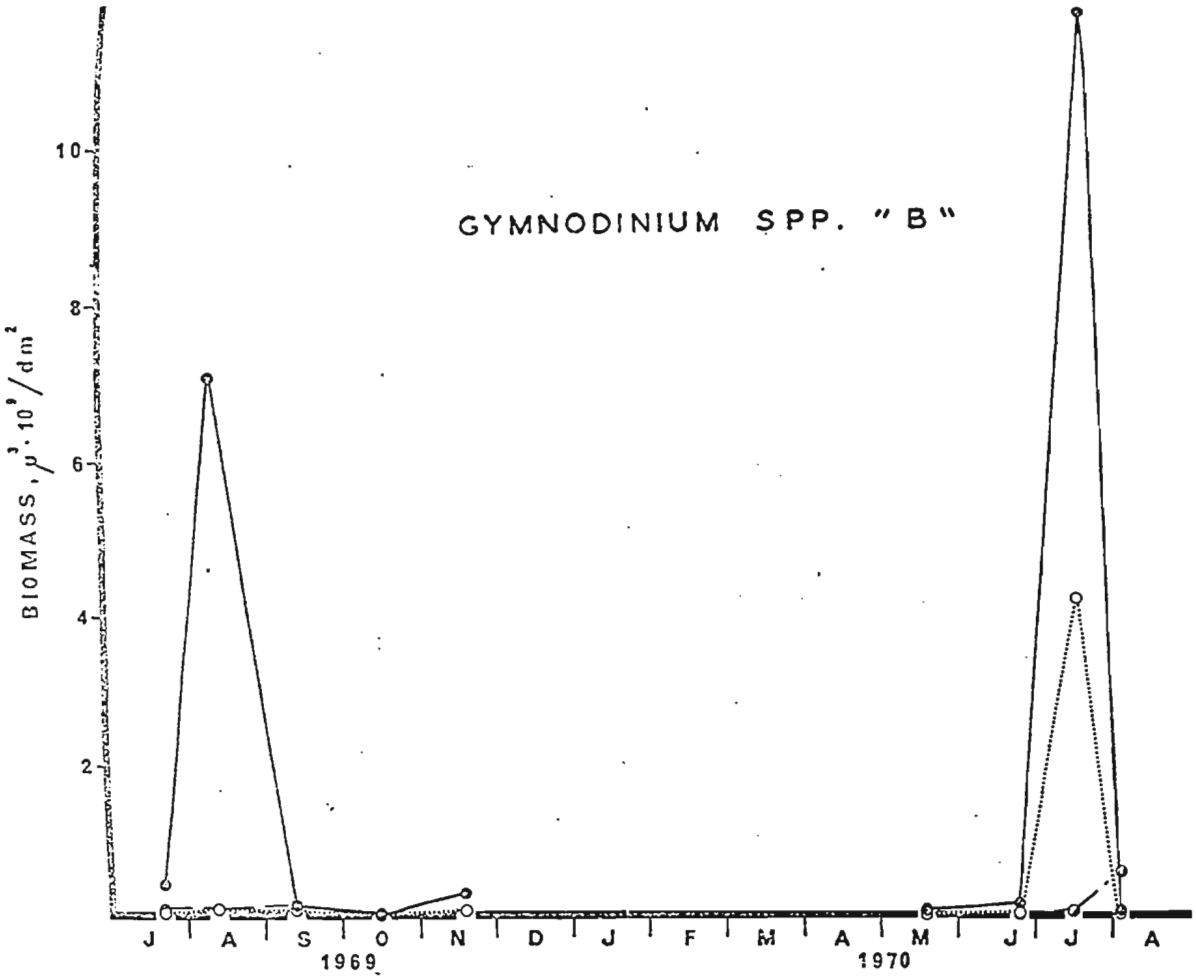
The second most abundant unarmoured dinoflagellate was Gyrodinium spirale (Table VII), a medium to large, elongated, biconical form. This species was most abundant at Aquaforte Harbour in all months except May. Generally, it was noted that the greatest biomasses, by far, occurred in May, even though

Figure 22. Comparison of the biomasses of Gymnodinium spp. "B" at the three stations.

___ Station 1, St. John's Harbour

... Station 2, St. John's Harbour

--- Aquaforte Harbour


GYMNODINIUM SPP. "B"
BIOMASS, $\mu^3 \cdot 10^9/dm^2$
10
8
6
4
2
J
A
S
O
N
D
J
F
M
A
M
J
J
A
1969
1970

the percentages did not show that the species contributed a great deal to the dinophycean population; they were only 3, 10 and 12%, respectively for Station 1, Station 2 and Aquaforte (Appendix II). The distribution was similar at the three locations: the population decreased in August of both years, and the species was absent in October. It was observed that G. spirale was concentrated at 10 and 22m.

Gymnodinium pygmaeum

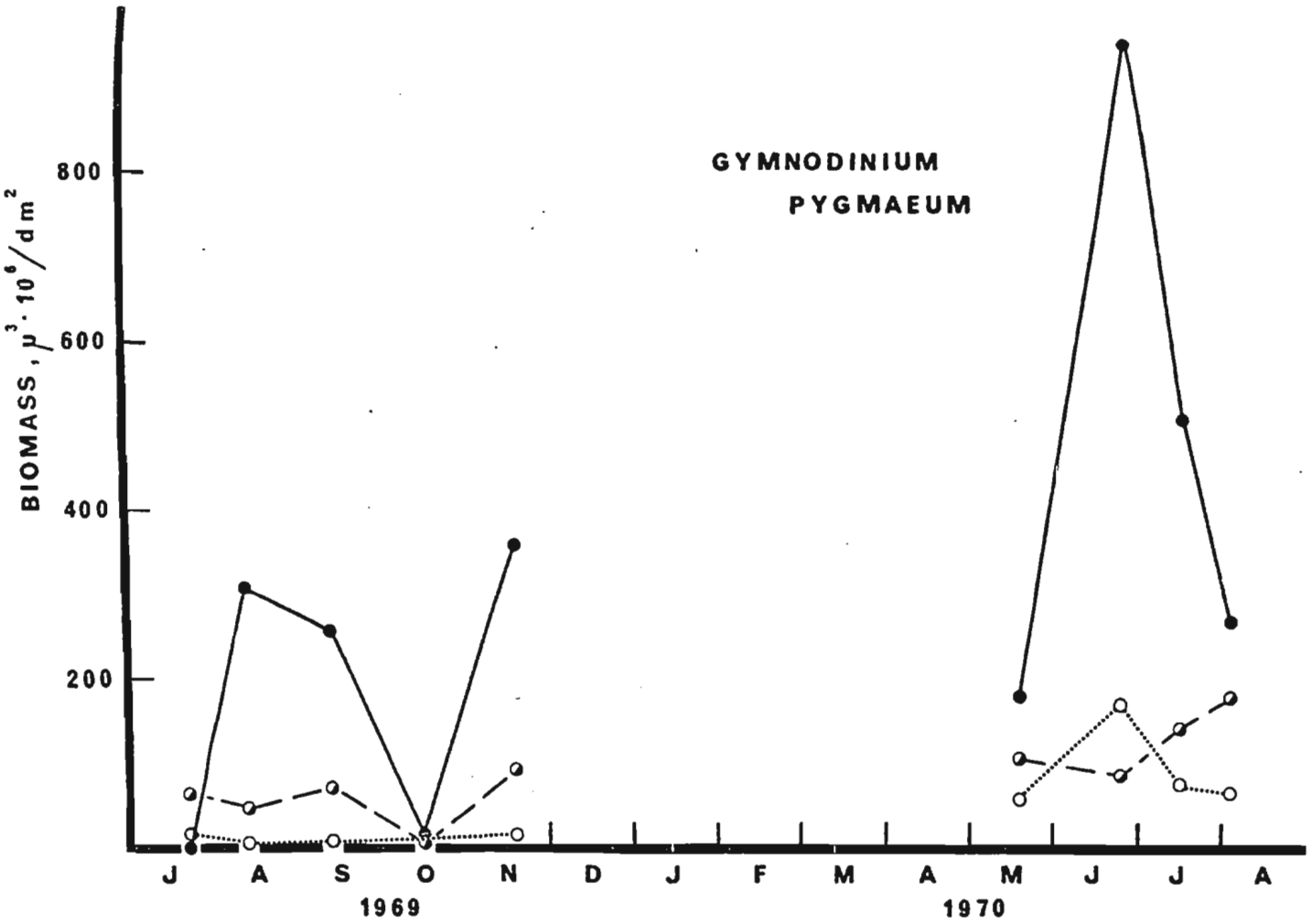
Another small unarmoured dinoflagellate, Gymnodinium pygmaeum, was found to be of significance. It was most abundant at Station 1 (Figure 23 and Table VII), where it constituted a significant portion of the dinophycean population (Appendix II); otherwise, its existence was negligible. Its greatest biomass at both stations in St. John's Harbour occurred in June, followed by a decrease in 1970. In 1969, another maximum was observed in November. At Aquaforte the species maintained its low biomass throughout the summer, but attained a small maximum in November, 1969, and in August, 1970. The species tended to be concentrated at the greater depths, particularly at 22m.

Figure 23. Comparison of the biomasses of Gymnodinium pygmaeum at the three stations.

——— Station 1, St. John's Harbour

... Station 2, St. John's Harbour

--- Aquaforte Harbour


GYMNODINIUM
PYGMAEUM
BIOMASS , $\mu^3 \cdot 10^6 / dm^2$
800
600
400
200
J
A
S
O
N
D
J
F
M
A
M
J
J
A
1969
1970

DISCUSSION

Circulation

According to Bowden's (1964) classification of estuarine circulation, St. John's Harbour has a "two-layer flow with entrainment" type of circulation, i.e., a one-way movement of salt water upwards. The outgoing river water on the surface is compensated for by the incoming saline water, which mixes upward with the freshwater along the length of the estuary. Fjords are included as a variation of this circulation pattern, with a limited amount of vertical mixing from an intermediate layer. This tends to obliterate the sharp decrease in salinity at the interface between the two layers, as is apparent from the salinity profiles interpolated from Table II. The bottom layers act as a reservoir with little water movement.

According to the same classification, Aquaforte Harbour has a "two-layer flow with vertical mixing" type of circulation. The level in the water column at which the seaward-flowing layer meets the landward-flowing layer is usually at mid-depth. Consequently, salinity profiles show a continuous increase in salinity from surface to bottom with the greatest increase per meter found at the mid-depth. The salinities at Aquaforte Harbour (Table II) do show a gradual increase with depth, except where heavy precipitation or ice has greatly distorted the expected surface reading. The fact that the river discharge

can be of little significance is another characteristic of this type of circulation. This is particularly true at Aquaforte Harbour since the outflow volume of Aquaforte River is small compared with the volume of the harbour basin.

In order for a phytoplankton population to flourish, as during a spring bloom, a fairly stable water column must develop so that the population is retained in the euphotic zone (Barlow, 1958). In lakes, and in the open sea, this is accomplished by a warming of the surface layers and the establishment of a thermocline. In estuaries, the river-tidal flow makes this type of stability difficult to attain. Here the salinity factor is more important; stability develops as a less saline region becomes established in the surface layers.

The ideal situation exists when there is a cycle of low and high stabilities. During the winter months there is a period of low stability, and the euphotic zone is replenished with nutrients. This is followed by a period of high stability during the spring, and the existing population in the euphotic zone exhibits an increase in production.

However, late summer blooms in the Duwamish estuary, Washington were not related to nutrients but rather to hydrographic conditions. A minimum river discharge enabled the euphotic zone to stabilize, retaining the population in the

upper layers (Welch, 1968). Parsons et al. (1969) concluded that the increased stability made possible by the influx of the Fraser River plume was a major factor which increased primary production. Similar conditions in Indian Arm, a fjord in British Columbia showed that 90% of production occurred in the stable surface layer, which was 5m thick (Gilmartin, 1964).

Salinity

Seasonal changes in salinity in estuarine waters are quite variable and are sometimes attributed mainly to land runoff. This usually affects only the surface waters because the estuarine circulation is such that land drainage flows over the surface of the water mass toward the open sea. The general decrease in salinity from Aquaforte Harbour to Station 2 to Station 1, St. John's Harbour is probably a factor of the decreasing distance from freshwater sources. In the areas studied, this runoff is not of prime importance, and other factors may be considered to explain the specific variations in salinity.

The abnormally low surface salinities at Station 1 in February were due to several inches of slush ice that had accumulated during onshore winds. At all three stations, the comparatively low salinities recorded in November could be attributed to the heavy rainfall and low evaporation during

that time of the year. An abnormally high precipitation in August, 1969 (8.28 inches; 21.0 cm) explains the decrease in salinities in early September.[1] The higher salinities occurring during the summer, especially in July, were the result of both evaporation and of little precipitation. In this month, in 1969, the rainfall was 3.90 inches (9.9 cm), and in 1970 it was 1.36 inches (3.5 cm).[1]

Temperature

At Station 2, temperatures were higher than at Station 1, St. John's Harbour. This is difficult to explain because the former station is more exposed to both wave and tidal action which continually renew the water column from the open sea. It may possibly be explained by the effluent of sea water which is used as a coolant in the city's auxiliary steam-generating plant located approximately 900 m from Station 2. The load of the plant can be 15,200 gallons per minute at peak operation, and is pumped into the intertidal area; the temperature of the water can be raised 11 C. However, the plant rarely operates a full day.

The fact that St. John's Harbour warms up earlier in the spring and cools off earlier in the fall than Aquaforte

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1. Precipitation readings were obtained from the Meteorological Office, St. John's Airport.

Harbour is directly attributable to the smaller volume and the more limited circulation with ocean water of the former. There seems to be a one-month lag in the changes in temperature at Aquaforte. In fact, the higher readings at Aquaforte Harbour in September may be due to the ability of the ocean proper to retain some of its summer heat, and to circulate it in the harbour through extensive flushing action.

Bodies of water often become thermally stratified in late summer as the surface layers become warmed and circulate above the colder bottom layers. A thermocline thus becomes established between the two layers. Higher water temperatures were recorded in 1970 than in 1969. This probably explains why a less definite stratification was evident in 1969 at Station 1, St. John's Harbour. However, Figure 8 does show a slight stratification in August, 1969 where a difference of 4.1 C was recorded between 15 and 22m. There is also evidence of stratification between 5 and 10m in September, 1969. The downward displacement of the colder stratified layer from July to August in 1970 shows the progressive warming of the upper layers. At Aquaforte Harbour, the August, 1969 thermocline may have been preceeded in July by a colder stratified layer closer to the surface, where a difference of 3.3 C was noted between 5 and 10m. At Station 2, the water was too turbulent to permit stabilization of the water column.

The almost uniform temperature from surface to 22m, recorded in October at Station 1, St. John's Harbour and in September at Aquaforte Harbour, would seem to indicate the complete breakdown of the stratified water column and the recirculation of the water during the fall overturn.

Oxygen Correlation with Phytoplankton Productivity

When the equation used to calculate the phytoplankton biomass under a square decimeter of surface area was applied to the oxygen data, coefficients of correlation between the two parameters were 0.39, 0.29 and 0.29 for Station 1 and 2, St. John's Harbour and Aquaforte Harbour, respectively. These r values proved to be not statistically significant. There are several reasons for this discrepancy. In enumerating the individual cells, no distinction was made between autotrophic and heterotrophic species. However, nonpigmented cells, especially among the diatoms and armoured dinoflagellates were not counted.

On manyoccasions, sampling took place below the depth of effective light penetration, as approximately indicated by the Secchi disc depths. Many of the specimens counted were probably utilizing oxygen in respiration, thereby reducing the expected oxygen levels. It may further be concluded that, since the effect of respiration was excluded from these

experiments, the biomasses determined only at the surface and 5m (the euphotic zone) would still not show a correlation with the oxygen readings. The effect of increasing oxygen concentrations in the surface waters as a result of turbulence of the oxygen exchange at the air-water interface would further complicate a correlation between biomass and phytoplankton production.

Volume as a Parameter of Biomass

Riley (1941b) discussed the hypothetical ideal that ecologists have in mind when measuring phytoplankton populations: the "biomass" and "volume of cell protoplasm" was the object of their experiments.

Biomass, as algal volume rather than cell numbers, is a more meaningful measurement since cell sizes vary from species to species. Furthermore, the average size of cells may vary from season to season as different phytoplankters become dominant.

Paasche (1960) found that phytoplankton production correlated better with cell surface area than with cell volume. This was because the cytoplasm of many cells, especially diatoms, is confined to the area between the large central vacuole and the cell wall. However, when chlorophyll was used as a measurement of standing crop, cell volume had a higher correlation with production than did cell area: 0.85 compared with 0.56 (Hobson, 1966). When pure cultures were used in experiments by Mullin et al. (1966), cell volume was found to give a better estimate of cell carbon than did surface area. Saifullah (1969) also found that cell volume had a higher correlation with cell carbon, chlorophyll and particulate phosphorus than with cell surface area or cell numbers. For

comparison of data, Cushing's (1958) standard equivalents showed that 1 mm^3 algal volume equaled 0.100 - 0.125 mg C. However, even this becomes debatable when the data of Mullin et al. (1966) are analysed. They found that for small species the carbon content can be 20-25% of the volume, while for large species it can be only 3-5%. The most satisfactory method seems to be the one applied by Strathmann (1967), where plasma volumes are a more precise estimate of cell carbon than are cell volumes.

Nevertheless, phytoplankton cell volume can be an indicator of biological productivity. If the general trend of seasonal progression is considered, the volume is closely correlated with both chlorophyll and C^{14} determinations (Rodhe et al., 1956). Riley (1941b) found that plant pigments had the highest correlation with other types of measurements of production, and therefore were most representative of phytoplankton abundance. The correlation of plant pigments with volume was highly significant.

Hasle (1969) suggested that the measurement used to estimate the standing stock may be dependent on the aim of the particular phytoplankton investigation.

Variability of Volumes Within Species

a. Comparison within the literature

It has been suggested by Holmes et al. (1969) that at least twenty-five random cells be measured to obtain the mean cell volume for a species. This figure was used as a guideline for each sample in the present study. However, frequently for the larger species, this quantity was not available in the counting chamber.

Many authors indicated the volumes which they calculated for their specific sampling areas: Paasche (1960), McAllister et al. (1961), Parsons et al. (1961), McAllister et al. (1963), Nauwerck (1963), Pavoni (1963), Smayda (1965), Mullin et al. (1966), Hasle (1969), Saifullah (1969) and Vollenweider (1969b). Table IX gives a comparison of volumes of species identified in this study with those available from the literature. It is obvious from previous calculations of volumes that different species were being considered in many instances. Thus volume might be another taxonomic criterion, especially in differentiating between subspecies. Besides being used as a taxonomic reference, an analysis of the comparative volumes tests the validity of incorporating previous data into current research.

Pavoni's (1963) Asterionella formosa does not agree

Table IX. Comparative data on cell volumes (μ^3) selected from the literature.

	μ-cells	Asterionella formosa	Chaetoceros debilis	Ch. decipiens	Ch. gracilis	Ch. socialis	Coscinodiscus centralis	C. radiatus	Eucampia zodiacus	Fragilaria crotonensis	Leptocylindrus danicus	Nitzschia closterium	N. delicatissima	N. seriata
present data	30–60	500–800	1100–2100	14,000–27,000	20	130–140	1,300,000–4,700,000	10,000–57,000	14,000–23,000	600	2300–4900	20–50	130–150	900–1500
Lohmann 1908														2000
Bernard 1938														570
Bogorov 1959				3000										500
Paasche 1960			1400	9700	230		2,400,000					v.min. 18	70	2500
McAllister et al. 1961							7,350,000	12,500					500	
Parsons et al. 1961							Ch. sp. 3,420,000							
Vives and Fraga 1961				3790										1600
McAllister et al. 1963														
Nauwerck 1963	10	800												
Pavoni 1963		290								800				
Smayda 1965			1290	2035		305			5388		1840	121	51	763
Bernhard and Rampi 1967				33,000										2400
Hasle 1969												140		
Findenegg (unpubl.) in Vollenweider 1969b		700								200,000 /1mm				
Saifullah 1969			1695	9843						1,500,000 /(?)				

(Cont'd.)

Table IX. (Cont'd)

	Rhizosolenia alata	R. fragilissima	R. hebetata f. semispina	R. shrubsolei	Synedra ulna	Thalassiosira nordenskiöldii	Thalassiothrix longissima	Tabellaria fenestrata	T. flocculosa	Gyrodinium spirale	Rhodomonas
present data	f.grac. 8,000	41,000-59,000	6,000-42,000	70,000-270,000	7,000-11,000	6,000-7,000	7,000-16,000	1,000-4,000	7,000-20,000	4,000-21,000	R.sp. 70-120
Lohmann 1908			34,000								
Bernard 1938											
Bogorov 1959											
Paasche 1960	37,000		18,000				87,500				
McAllister et al. 1961						11,000					
Parsons et al. 1961											
Vives and Fraga 1961											
McAllister et al. 1963									G.spirale(?) 120,000		
Nauwerck 1963								3,000	2,000		R.spp. 100-250
Pavoni 1963										R.lacrustris 100-190	
Smayda 1965	65,160	4,040	Rh.imbricata v.shrubsolei 62,000								
Bernhard and Rampi 1967			1,100,000,000								
Hasle 1969	60,000		260,000								
Findenegg (unpubl.) in Vollenweider 169b					v.danica 5,000			4,000		R.lacrustris 200	
Saifullah 1969						7,764					

with any of the volumes found in the literature or in this study. Chaetoceros decipiens appeared to be an extremely variable species; the volume of the one described in this study is comparable to only one of the six volumes cited in the literature. It is indeed interesting that the type found in this study differed from that found in St. Margaret's Bay by Saifullah (1969). Discrepancies may have arisen in omitting the volume of the bristles. Considering Chaetoceros gracilis, Paasche (1960) was not describing the same species as that found in this study; the dimensions measured here are similar to those noted in the Baie des Chaleurs by Brunel (1962). The species of Chaetoceros socialis was smaller than that noted by Smayda (1965), but again the dimensions were more in line with Brunel's (1962). The Eucampia zodiacus described in this study differs from Smayda's (1965); however, two distinct forms are noted in most taxonomic references. The volumes of Leptocylindrus danicus were only marginally comparable. The Nitzschia closterium described in this study could possibly be of the variety minutissima noted by Smayda (1965). The range in volume of Nitzschia delicatissima exibited by the three authors shows the variability of this diatom. The volume of the form gracillima of Rhizosolenia alata indicated how this differs from the type species. Smayda's (1965) Rhizosolenia fragillissima does not appear to be the same species described in this study. Two of the four authors describing Rhizosolenia hebetata f. semispina gave volumes which varied considerably from the present data. The Synedra ulna of this study is slightly larger than

the variety danica described by Findenegg (Vollenweider, 1969b). A considerable difference was observed in Paasche's (1960) Thalassiothrix longissima and the one encountered here; the latter was identified in Lebour (1930). The Tabellaria flocculosa described in this study was considerably larger than the one described by Nauwerck (1963). The Gyrodinium spirale (?) described by McAllister et al. (1963) was obviously not the same species described by Lebour (1930), from which the species of this study was identified. The form described by McAllister et al. (1963) was too large, even after taking into consideration the fact the Lebour's (1930) species varied considerably in size.

Nevertheless, some species did show volumes comparable to the published data. These were Chaetoceros debilis, Coscinodiscus centralis, C. radiatus, Fragilaria crotonensis, Nitzschia seriata, Rhizosolenia shrubsolei, Thalassiosira nordenskiöldii, Tabellaria fenestrata and Rhodomonas sp.

It should also be noted that the choice of geometric models contributes to the intraspecific variation in cell volume.

It can be concluded from the literature that the variation of cell volumes measured herein is significant enough to warrant the measurement of a species in each new area studied, and that previously-recorded volumes cannot be interpolated

into current research.

Few investigators have recorded a range of cell volume for the species measured. Pavoni (1963) and Saifullah (1969) acknowledged this phenomenon in determining biomass from volume. A general analysis of the variability of all volumes within a species in the present study indicates a two-fold difference between the lowest and highest recorded volumes (Table VI). This further necessitates the continuous monitoring of the algal volumes to establish seasonal and spatial variations in volumes.

b. Comparison within the present study

The net plankton were measured throughout the experiment, and an analysis of their interspecific volumes was made (Table X). The seasonal variation in size indicated that extensive year-round measurements are warranted. (It must be remembered that no data was available from December to April.) Also,significant differences at the two locations established that volumes at relatively close stations have to be measured separately.

Both Ceratium arcticum and C. longipes were approximately 10% larger at Aquaforte Harbour than at St. John's Harbour throughout the nine months of sampling except in September

Table X. Seasonal variation in the volume ($\mu^3.10^3$) of four species at St. John's Harbour and Aquaforte Harbour.

	1969					1970			
	JUL	AUG	SEP	OCT	NOV	MAY	JUN	JUL	AUG
Ceratium arcticum									
St. John's Harbour	101	90	126	-	90	99	92	103	92
Aquaforte Harbour	114	99	95	-	97	120	116	106	97
Ceratium longipes									
St. John's Harbour	81	97	99	76	91	93	107	105	92
Aquaforte Harbour	107	104	87	90	97	118	106	137	100
Ceratium fusus									
St. John's Harbour	75	78	67	96	86	96	84	75	77
Aquaforte Harbour	-	73	66	90	77	-	-	-	61
Peridinium depressum									
St. John's Harbour	757	770	726	687	889	1375	946	832	843
Aquaforte Harbour	721	797	687	560	548	1145	976	1000	844

when they were both considerably larger at St. John's Harbour. The reverse is true for C. fusus, where the species was consistently larger in St. John's Harbour. As for the seasonal variation, C. arcticum appeared to be smallest in August and November at St. John's Harbour, and in September at Aquaforte Harbour; it was largest in September at St. John's Harbour, and in May at Aquaforte. C. longipes was smallest in early fall and largest in mid-summer at both harbours. C. fusus was smallest in late summer and largest in October at both harbours. The largest cells of C. arcticum had volumes 30% greater than the smallest cells; C. longipes volumes were 45% greater; and C. fusus volumes were 40% greater. Therefore, it would appear to be mandatory to take seasonal variation into account when measuring these species.

Although Peridinium depressum showed no significant difference in size between the two locations, a distinct seasonal variation existed with the largest specimens appearing in May and the smallest in late fall at both harbours. Throughout the sampling period, the volumes of the largest cells were 60% greater than the smallest cells.

Seasonal Distribution of the Phytoplankton

The classical annual phytoplankton cycle in the temperate oceanic latitudes is bimodal with spring and fall peaks; however, this pattern is not consistently apparent in coastal waters. Bigelow (1926) described a third summer diatom maximum in Massachusetts Bay, as did Fish (1925) in the waters near Woods Hole. Patten et al. (1963) described a "six-diversity pulse" in the lower Chesapeake Bay. In Long Island Sound, Conover (1956) reported a large late-winter flowering, and smaller summer and early fall flowerings. Riley (1952) described a similar seasonal distribution, occurring in Block Island Sound, as typical for temperate coastal waters.

In St. John's Harbour, three distinct rises in the phytoplankton population occurred; in Aquaforte Harbour, four were evident. However, even though they occurred at the same time, the groups of algae involved were different.

At both St. John's Harbour stations, the largest bloom occurred in July, when the Euglenophyceae were dominant. This is comparable to Saifullah's (1969) study in St. Margaret's Bay, where one of the four maxima was a dominance of micro-flagellates (Euglenophyceae, Chrysophyceae and Chlorophyceae) in June. In the inner Oslo Harbour, Braarud and Bursa (1935) described flagellates of all types as the most prominant species

in July. The summer increase in St. John's Harbour was followed in November by a small increase in biomass which was attributed to the Dinophyceae. The spring bloom which was considerably smaller than the summer one, consisted primarily of dinoflagellates. Dominance of the Dinophyceae in the spring seems peculiar to this situation. Perhaps these dinoflagellates are better adapted to survive reduced salinity conditions and high nutrient content in the waters of the harbour, than are the diatoms.

At Aquaforte Harbour, the spring bloom had the greatest biomass when the diatoms were dominant, the typical temperate water situation. Another small diatom increase occurred in July. The rich diatom population of the inner Oslo Harbour in July is hardly comparable to that in Aquaforte since nutrients from sewage effluents permitted this group to compete with other species in the former location. In August, at Aquaforte, the dinoflagellates were prevalent. In the outer Oslo Fjord, the ceratia were the dominant group during the summer(Braarud, 1945). Saifullah (1969) reported the dinoflagellates as the dominant group in July at St. Margaret's Bay. Conover (1956) attributed summer flowerings to dinoflagellates and smaller flagellates. As in St. John's Harbour, a small dinophycean population prevailed in November. This phenomenon is comparable to Platt's (1970) findings in the polluted Bedford Basin, when dinoflagellates continued their dominance during the fall.

Phytogeographical Distribution of the Phytoplankton

Excluding the Chlorophyceae and the Cryptophyceae, which are primarily freshwater species, and the unarmoured dinoflagellates, except Gyrodinium spirale, many of which were difficult if not impossible to identify, there remained 1 Xanthophyceae, 31 Bacillariophyceae, 12 Dinophyceae and 1 Chrysophyceae to group into phytogeographical zones according to the classification of Fish (1925), Burkholder (1932), Gran and Braarud (1935), Brunel (1962) and Movchan (1970).

The results are shown in Table XI:

Table XI. Phytogeographical distribution of the species found in St. John's Harbour and Aquaforte Harbour.

Phytogeographical Zone	Xantho-phyceae	Bacillario-phyceae	Chryso-phyceae	Dino-phyceae	Total
arctic oceanic				1	1
boreal oceanic	1	9	1	5	16
temperate oceanic		2		1	3
arctic neritic		1			1
boreal neritic		11		4	15
temperate neritic		3		1	4
					40

These data clearly indicate that the most abundant forms are contained within the arctic-boreal group. This agrees with

Gran and Braarud's (1935) study in the Bay of Fundy and in the Gulf of Maine, Iselin's (1930) study in the coastal waters off Labrador, and Movchan's (1970) study of the distribution of diatoms around the Grand Banks. These authors also found that ecologically the neritic forms were more important than the oceanic forms; Movchan (1970) listed 60% of his diatoms as neritic and 30% as oceanic. This did not hold true for the present study since both forms were equally distributed.

Considering the phytoplankton groups separately, the diatom distribution was similar to Movchan's (1970) findings, consisting primarily of arctic-boreal species, while the dinoflagellate distribution differed. Movchan (1970) found that most of his species were tropical forms, while this study found them to belong to the boreal oceanic group, thereby indicating that the Gulf Stream did not influence the composition of the phytoplankton, but that the Labrador Current was responsible for the presence of these dinoflagellates in the harbours of the Avalon Peninsula.[2]

Further south, Burkholder (1932) found the temperate neritic group of diatoms to be most abundant in Penobscot and

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2. The bulk of the Labrador Current follows the outer edge of the northeastern section of the Grand Banks where it meets the warmer and more saline Gulf Stream, but a small part of the current finds its way along the Avalon Peninsula (Iselin, 1930). It is characterized by temperatures of -1 to 0 C, and a salinity of 33°/oo. By the time it reaches the northeastern section of the Banks, the temperature is 0 to 3 C (Movchan, 1967).

Frenchmans Bays in Maine, as did Fish (1925) in the waters off Woods Hole.

As would be expected in a semi-enclosed estuarine environment, many tychopelagic forms were identified: seven species of green algae and six species of diatoms, possibly including some of the naviculoids. The greatest abundance of this group was recorded at Station 1, St. John's Harbour.

Phytoplankton Distribution According to Size

In 1903, Lohmann defined nannoplankton as that portion of the population which will pass through the pores of a fine plankton net (Yentsch and Ryther, 1959). Cushing et al. (1958) defined microplankton, nannoplankton and ultraplankton by the sizes $>60\mu$, $>5\mu$, and $<5\mu$, respectively. Strickland (1960) defined nannoplankton as organisms 10 to 50μ, and ultraplankton as those 0.5 to 10μ for the largest dimension.

For the purposes of this paper, ultraplankton is defined as those plankters with one side measuring 5μ or less for the smallest dimension, and having a volume of less than $150\mu^3$. Net plankton is that which can be retained in the No. 25 plankton net, as determined from the qualitative plankton tow. Of the 85 species and four categories identified in this study, 9 species plus μ-cells and flagellates "B" were ultraplankters, 45 species plus all naviculoids, gymnodinians and flagellates "A" were nannoplankters, and 31 were net plankters.

Some workers have claimed net samples to be representative of the phytoplankton population. In examining a centrifuged water sample, Burkholder (1932) did not find any species additional to those taken with a No. 20 plankton net, and consequently based all his data on the net collection. However, it is now generally agreed that a substantial quantity of the

population can be lost through the finest net.

Riley et al. (1949) described swarms of flagellates having a size range of 3 to 15μ in freshwater samples. Counts indicated their abundnace of the order of 16 million cells per liter. He attributed the discrepancies between cell counts and plant pigments in Long Island Sound to the presence of these nannoplankters.

Hulburt et al. (1960) recognized the importance of nannoplankton or μ-plankton in the Sargasso Sea. They were describing a group 1 to 5μ in size, consisting of 3.5μ flagellates and thick-walled spherical cells, probably fungal spores. The biomass of this group and the larger phytoplankton was found to be similar, but they could only speculate on the photosynthetic activity of this group since their autotrophic nature was not known. Analyzing the chlorophyll a concentrations, they discovered that, accordingto the chlorophyll content of individual cells, the larger phytoplankton comprised only a small fraction of the number of autotrophic organisms.

Rodhe et al. (1956) determined nannoplankters as any algae equal to or smaller than 100μ in greatest dimension, and found that their significance was greater in the standing crop than in the production of organic matter. Hence, the importance of the nannoplankters in production seems to be even greater

than it would be assumed from the standing crop. Findenegg (1965a) concluded that nannoplankton was more active than net plankton in the assimilation of carbon, because of its greater surface to volume ratio, which increased the uptake of nutrients. In a body of water dominated by smaller algae, both turnover and assimilation rates are higher, regardless of the standing crop.

Many scientists have reported on the relative abundance of nannoplankton in various environments, as summarized in Table XII.

It is difficult to conclude, as many authors cited above have done, which plankton size dominated the population in the present study. In order to compare the data with previous experiments, it was necessary to combine the ultra- and the nannoplankton. The percentages in Table XIII clearly indicate the inconsistencies in any distributional pattern.

Certainly, the nannoplankton was generally the most abundant during the summer months at both stations in St. John's Harbour. At Station 1, they comprised 95 and 99% of the population in July and August of both years; in fact, they dominated the phytoplankton in all months except May when 69% of the population was net plankton. At Station 2, the nannoplankton comprised a smaller portion of the population: 90% in August,

Table XII. Results of some nanno- and net plankton studies in various environments.

Source	Location	Size Distinction Between Nanno- and Net Plankton	Results
Rodhe et al. (1956)	Lake Erken, Sweden	70μ	Nannoplankton contributed to 95-98% of primary production (C^{14}) in spring; net plankton contributed to 56-81% of primary production (C^{14}) in July and August.
Willén (1959)	Görväln Bay, Sweden	60μ	Nannoplankton was dominant during most of the year; net plankton was dominant during spring bloom and August-September.
Gilmartin (1964)	Indian Arm, British Columbia	55μ	Nannoplankton accounted for 99% of primary production (C^{14}) from May to June.
Miller and Moore (1953)	Florida Strait	-	Biomass of nannoplankton can be 1,000 times that of net plankton.
Yentsch and Ryther (1959)	Vineyard Sound	65μ	Nannoplankton comprised 89% of the total cell count.
Walsh (1969)	Antarctic Convergence and Ross Sea	-	Microflagellates comprised 99% of the total cell count.

Table XIII. Percentage of total biomass represented by three sizes of phytoplankton at each station.

	% ultraplankton	% nannoplankton		% net plankton
Station 1, St John's Harbour				
July, 1969	2.3	97.4	(99.7)	0.4
August	14.9	84.5	(99.4)	0.6
September	55.1	26.1	(81.2)	18.9
October	61.8	23.7	(85.5)	14.5
November	37.8	27.8	(65.5)	34.3
May, 1970	15.0	16.0	(31.0)	69.0
June	15.6	71.0	(86.6)	13.4
July	2.1	96.8	(98.9)	1.1
August	52.2	42.5	(94.7)	5.3
Station 2, St. John's Harbour				
July, 1969	4.6	48.4	(53.0)	47.0
August	6.0	82.9	(88.9)	11.1
September	41.6	16.0	(57.6)	42.4
October	-	-	-	-
November	41.8	19.3	(61.1)	38.9
May, 1970	10.7	27.0	(37.7)	62.4
June	11.0	26.5	(37.5)	62.5
July	6.4	88.5	(94.9)	5.1
August	39.3	29.5	(68.8)	31.1
Aquaforte Harbour				
July, 1969	1.6	60.8	(62.4)	37.6
August	14.7	10.2	(24.9)	75.1
September	51.6	17.7	(69.3)	30.7
October	2.5	62.3	(64.8)	35.2
November	12.7	18.9	(31.6)	68.4
May, 1970	4.7	50.2	(54.9)	45.1
June	4.6	39.7	(44.3)	55.8
July	5.3	36.2	(41.5)	58.5
August	25.9	17.0	(42.9)	57.1

Figures in brackets represent both ultra- and nannoplankton.

1969 and 95% in July, 1970, and was considerably lower in the other summer months: 53 and 69%. Net plankton dominated the population in both May and June with percentages of 62 and 63%. Thus, the net plankton was a relatively insignificant group in St. John's Harbour

At Aquaforte Harbour, the net plankton was the dominant group, comprising a monthly average of 53% of the biomass. It was least important in September and October when it comprised only 31 and 35% of the population. When compared with the other two stations, the May net plankton population was much smaller, 45% of the biomass.

The ultraplankton, as represented by the Chlorophyceae and the Cryptophyceae, tended to increase in importance in early fall at all stations, frequently comprising over half of the biomass.

The present study partially agrees with the findings of Gilmartin (1964), Miller and Moore (1953), and of Yentsch and Ryther (1959), regarding the predominance of nannoplankton in coastal environments (Table XII), while recognizing the fact that different methods were used to measure this quantity, i.e., C^{14} and cell numbers. St. John's Harbour had a monthly average nannoplankton biomass of 83% for Station 1, and 62% for Station 2. However, at Aquaforte Harbour, the percentage

biomass was much lower, 47%.

A similarity with Willén's (1959) distributional pattern, which was incidentally in direct contrast with the conclusions of Rodhe et al. (1956) for freshwater, is the relative unimportance of the nannoplankton during the spring diatom bloom. This is the time when the net plankton reached its peak at St. John's Harbour, comprising 62 and 69% of the biomass at the two stations.

Although the seasonal distribution cannot be dealt with conclusively because of the lack of winter data, the results of this study seem to disagree with the premise of Yentsch and Ryther (1959) and of Birge and Juday (1922) that nannoplankton exibits no seasonal trends. Its prevalence during the summer months, especially in St. John's Harbour, supports this fact.

Miller and Moore (1953) summarized the distribution of net plankton in various latitudes, as described by previous authors (Table XIV).

Table XIV. Percentage of phytoplankton biomass caught by a No. 25 plankton net. From Yentsch and Ryther (1959).

Scoresby Sound, East Greenland	66%
Off Plymouth, England	10-26%
Long Island Sound	9-56%
Vineyard Sound	2-47%
New South Wales, Austra lia	3- 4%
Tortugas	1%

The range of the percentage net plankton over the sampling period agrees with Yentsch and Ryther's (1959) interpretation of the geographic distribution. Net retention of the phytoplankton in the higher latitudes is quite high, in contrast with that of the lower latitudes, while in the more temperate regions the percentages include both extremes, e.g., 0.4 to 69% for Station 1; 5.1 to 62% for Station 2, St. John's Harbour; and 30.7 to 75.1% for Aquaforte Harbour. According to Yentsch and Ryther (1959), the extreme range of percentages is explained partially by the prevalence of small planktonic forms in estuaries.

Eutrophication

The following discussion is concerned more specifically with eutrophication as dealt with in the Introduction. Various indices of this phenomenon are discussed in detail as they determine the extent of the enrichment process in St. John's Harbour.

a. Oxygen deficit in the bottom layers.

With the establishment of the thermocline during summer stagnation, a clinograde oxygen curve would be expected. This occurred to some degree during August of both years at Station 1, St. John's Harbour, based on measurements in ml/l and percentage saturation. However, in July at the same station, and in August, 1969 at Aquaforte Harbour, decreases in oxygen readings were noted only when calculated as percentage saturation.

Stagnation of the bottom layers was evident in months other than those with an established thermocline. Its prevalence during all summer months at Station 1 is indicative of inadequate circulation in the water column. On many occasions the percentage saturation showed a decrease when the ml/l did not.

Oxygen content is usually considered to be the most

important, single parameter of sewage-derived pollution (Anon., 1969). Fruh et al. (1966) cautioned against measuring oxygen directly, explaining that in a nonstatic environment, the rate of oxygen depletion was a more precise measurement. Thus, Sawyer's (1966) limnological interpretation of dissolved oxygen (Figure 2) is only partially applicable to the estuarine environment of this study. Figures 10 and 11 show a eutrophic condition for Station 1, St. John's Harbour, especially during the summer months, while the other stations assume oxygen values which are relatively uniform with depth, typical of the oligotrophic condition.

Welch (1968) noted a decrease in dissolved oxygen at 1m above the bottom of the Duwamish River to 1.2mg/l in August, 1963, and to 2.8mg/l in August, 1965; this was coincidental with the phytoplankton bloom. The dissolved oxygen data of Patten et al. (1963) for the bottom water of the lower Chesapeake Bay ranged from 1.03 to 3.05mg/l at five stations at the entrance to York River; the corresponding surface concentrations ranged from 8.18 to 8.90mg/l. Carpenter et al. (1969) noted that values less than 1ml/l of oxygen persisted longer in the bottom layer of the estuarine Potomac River than in the upper Chesapeake Bay. However, at the surface, near-saturation and supersaturation values occurred in both areas. The greatest deficit reported by Ketchum (1969) occurred at the mouth of the Hudson River where the oxygen content had decreased to 17% of saturation; offshore waters were generally supersaturated with

a maximum value of 121% at the surface off the tip of Long Island. In 1937, the oxygen percentages in the deepest part of the Bonne Fjord ranged from 0 to 20% (Braarud and Ruud, 1937). Braarud (1953) noted that the deep waters of the Bonne Fjord were devoid of oxygen in 1950 and had been replaced by hydrogen sulfide, while low oxygen values persisted in the inner Oslo Fjord.

The central basin of St. John's Harbour (Station 1) seems to be less eutrophic than were the estuaries cited above. The lowest oxygen recordings were observed in August and October, 1969: 3.72 and 3.42ml/l, respectively; the corresponding percentage saturations were 50and 52%.

According to Wibaut and Moens (1957), these percentages would represent an area which is "moderately polluted", i.e., 40 to 60% saturation (p. 11). They recorded percentage saturations below 10% in the Noordzeekanaal, during the summer, which they designated "heavily polluted", while near-bottom samples at stations located in the harbours of Ijmuiden off the North Sea were "moderately polluted".

In the comparable study of Bedford Basin, which Platt et al. (1970) designated as eutrophicated, several intrusions of ocean water occurred in 1967 culminating, in late November, in a complete replacement of the deep oxygen deficient water.

Meanwhile, the summer saturation values did not rise above 48% at 50m; the depth of the basin was 70m. By 1969, the late fall saturation values had decreased considerably: at 40m it was 20% and at 60m approximately 5%. An influx of ocean water occurred the following February, and by mid-March the entire water column was homogeneous. It was concluded that the spring bloom had also contributed to the oxygen content. The replenishment of the bottom waters in mid-November and the summer saturation values (50% and 52%) at 22m at Station 1, St. John's Harbour are similar to Platt's findings in 1967.

It is not known if the flushing of the stagnant bottom layer at Station 1 is an annual phenomenon. It would be interesting to determine if the replacement continued in the fall of every year, and if increasing eutrophication would render the 22m sample even more deficient in oxygen. At Station 1, the early August sample in 1970 was observed to have only 73% of saturation; further sampling might have revealed greater decreases of oxygen in the bottom layers.

b. Turbidity

Although the Secchi disc readings could not be compared with previous years, as has been done in more conclusive studies of turbidity by a variety of authors (Introduction, pp. 11-16), comparisons among the three locations produce some

interesting results. Minimum transparencies which developed in November and February were similar to those described by Willén (1959) in Görväln Bay of Lake Mälaren off the Baltic Sea. He correlated minimum visibility with the spring and autumn turnover as the circulation pattern developed.

Despite the overwhelming data against the correlation of Secchi disc readings with biological production in estuaries, some conclusions can be made from this study. Furthermore, if correlations can be drawn, it can be concluded that organic and inorganic particulate matter is not responsible for the increase in turbidity in this study, as it is in many estuaries along the Atlantic seaboard (Introduction).

The higher standing crops (Figure 12) at Station 1, St. John's Harbour correspond to the comparatively lower Secchi disc readings, especially during the summer months. A distinct lower reading occurred in May, only at Station 2 and Aquaforte Harbour, and coincided with the large biomass associated with the spring bloom. In June, at the same two stations, the Secchi disc readings at 19m or deeper could be associated with a decrease in biomass from the previous month. The above observations for May and June did not hold for Station 1. Even though a fairly large population was recorded in May, the Secchi disc reading was the highest for the entire study at that station (5m). The decrease in biomass for June was accompanied by a decrease in the disc reading.

It can be concluded from calculations of the extinction coefficients that the waters of Station 1, St. John's Harbour are more turbid than those of Bedford Basin(Platt et al., 1970), although it must be remembered that not all months were sampled in the present study. The annual average extinction coefficient at Bedford Basin was 0.3 as compared with 0.5 at Station 1. The average at Station 2 was 0.2; at Aquaforte Harbour it was 0.1. The summer Secchi disc readings at Station 1 varied from 3 to 4m. The disc values in the inner Oslo Fjord are comparable; in the summers of 1962-1965 they averaged 3m (Anon., 1968).

Although some generalizations are apparent, the results of this study of turbidity are not entirely conclusive since discrepancies develop when the individual extinction coefficients are correlated with the biomass. They might be more meaningful if further annual measurements of turbidity were carried out in these areas. Nevertheless, the increase in turbidity can be correlated with the high standing crop at St. John's Harbour during the summer months, and it can be assumed that sewage effluents are responsible for the enrichment process.

c. Standing crop and eutrophication

A review of the literature on the correlation between standing crop and trophic levels in lakes (Introduction, pp. 16-21) indicated that varying environments produced different

results. Lund (1969) and Findenegg and Ruttner in Vollenweider (1969a) definitely concluded that a correlation did not exist. Two extensive works by Findenegg (1965a) and Pavoni (1963) showed that a correlation was frequently, but not always, recorded. Nevertheless, in some cases incipient eutrophication was accompanied by great increases in biomass, e.g., Davis (1964), Holsinger (1955), Anderson in Fruh et al. (1966), and Straškraba and Straškrabová (1969).

In estuarine environments, nutrients from untreated sewage were responsible for the high standing crops and eutrophication in Bedford Basin, Nova Scotia (Platt et al., 1970), River Tyne, England (James and Head, 1970), and Oslo Harbour (Braarud, 1945).

In the present study, Station 1, St. John's Harbour had the highest average standing crop; it was 2.3 times that at Station 2, and 2.7 times that at Aquaforte Harbour. Therefore, according to this parameter, St. John's Harbour is more eutrophicated than Aquaforte Harbour. During July, 1970, the difference between the two harbours was more pronounced; the standing crop at Station 1 was 8.7 times that at Aquaforte. This last factor is more comparable to the data of Platt et al. (1970) when the annual standing crop at Bedford Basin was ten times that in nearby St. Margaret's Bay.

d. Nannoplankton association with trophic levels

According to many authors (Riley et al., 1949; Miller and Moore, 1953; Yentsch and Ryther, 1959; and Gilmartin, 1964), in estuarine environments, nannoplankton is more important than net plankton, in primary production, and as constituents of the standing crop. Since the nannoplankton was considerably more abundant, especially during the summer, at St. John's Harbour than at Aquaforte Harbour, it can be assumed that additional nutrients from domestic sewage were responsible for the growth of this group of plankton.

Pavoni (1963) went so far as to suggest a classification of trophic levels based on the mean percentage of nannoplankton present in the population (Figure 24). He found greater percentages of nannoplankton in the extreme environmental conditions of oligotrophy and hypertrophy; eutrophic conditions were dominated by the net plankton. He explained these findings on the basis that there are many more species of nannoplankton than net plankton.

According to Pavoni's (1963) classification, oligotrophic conditions are represented by 30-90% nannoplankton at one end of the scale, while hypertrophic conditions are represented by 20-90% nannoplankton at the other end of the scale (Figure 24). Judging from the algal composition (section f. Euglenophyceae,

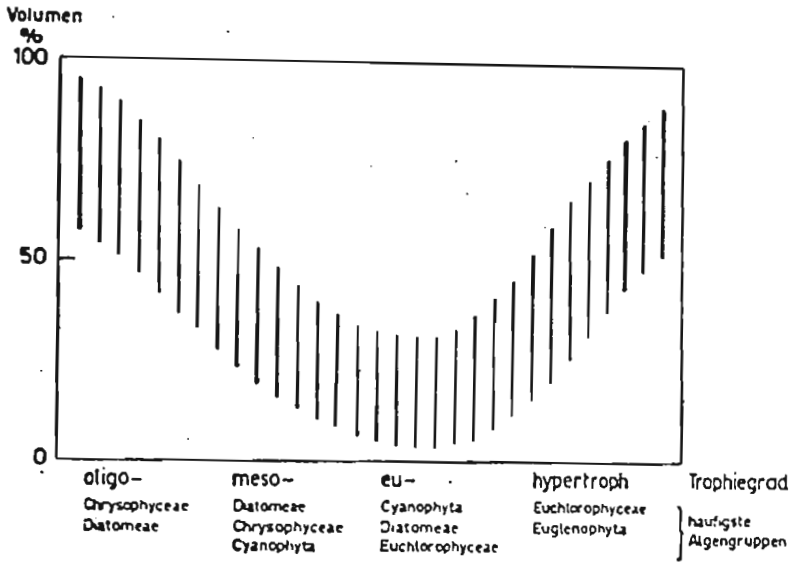

Figure 24. Percentage biomass of nannoplankton compared to the total phytoplankton in waters of different degrees of trophy (schematic representation). From Pavoni (1963).

and algal groups of Figure 24), these percentages place both St. John's and Aquaforte Harbours in the hypertrophic end of the spectrum. Only Station 1, St. John's Harbour falls into the extreme of the hypertrophic range, with nannoplankton comprising over 80% of the population during most of the sampling period. However, the relevancy of this classification is questionable since it applies to limnological data.

e. Distribution of some major species and trophic levels

Microflagellates, Chlorophyceae (?)

Lillick (1937) and Smayda (1957) noted the consistent abundance of microflagellates in inshore waters, in Vineyard Sound and in lower Narragansett Bay, respectively. Braarud (1945) noted that green flagellates increased considerably in importance in polluted waters, while they were only occasionally found in coastal plankton. Small microflagellates (9-11μ) in St. Margaret's Bay, Nova Scotia constituted 93% of the total population in June (Saifullah, 1969). This is certainly comparable to the results of this study which showed that flagellates "A", flagellates "B", μ-cells (Table VII), and Pyramimonas sp. were considerably more abundant in the central basin (Station 1) of St. John's Harbour than at the other two stations.

Asterionella formosa

Asterionella formosa was described by Patrick and Reimer (1966) as a freshwater species most often associated with eutrophic or mesotrophic conditions. In this study, the species was found in large numbers only at Station 2, and then primarily in September (426 cells/l at 22m) and November (973 cells/l at 22m; Table VII). This species was also noted in the polluted

harbours of Ijmuiden and in the Noordzeekanaal (Wibaut and Moens, 1938). Another closely related species, A. gracillima, was described by Rice (1938) in the River Thames as having a spring and sometimes a fall maximum.

Chaetoceros spp.

The results from this study showed that Chaetoceros debilis occurred in greatest abundance at Aquaforte Harbour, while Ch. decipiens and Ch. socialis were more abundant at Station 1, St. John's Harbour. This is in contrast with the finding of Platt et al. (1970) that these three species appeared to show no difference in distribution in the polluted waters of Bedford Basin and in the relatively unpolluted waters of St. Margaret's Bay. However, these three species of Chaetoceros were among those found to be tolerant of the effluents from the harbours at Ijmuiden (Wibaut and Moens, 1938). In the 1935 fall diatom bloom in Oslo Fjord, Ch. decipiens and Ch. debilis were represented: especially the latter species which had its greatest populations inside the Oslo islands. In 1938, the Chaetoceros spp. were more numerous in Oslo Harbour than outside (Braarud, 1945). This last finding partially agrees with those of the present study.

Leptocylindrus danicus

Leptocylindrus danicus was reported by Braarud (1945)

just outside the Oslo Harbour in concentrations at the surface, of over 3 million cells/l in August, 1935; in September, 10 million cells/l were recorded. This species was also described from the harbours of Ijmuiden; however, they did not penetrate the Noordzeekanaal (Wibaut and Moens, 1938). L. danicus was not represented in the present study in any concentrations approaching those in Oslo Fjord. The largest population was in July at the surface at Aquaforte (1,261 cells/l: Table VII). The Aquaforte population was always larger than that from St. John's.

Nitzschia spp.

Both Nitzschia closterium and N. seriata occurred in higher numbers at Aquaforte Harbour. The concentrations were fairly low: 191 cells/l at 22m in July, 1969 for N. closterium, and 186 cells/l at 10m in July, 1970 for N. seriata (Table VII). This disagrees with the findings for N. closterium in the Oslo Fjord (Braarud, 1945). It was an important constituent of the population in the fall of 1935, with 41,000 cells/l at the surface in the inner Oslo Harbour. In the summer of 1936, it was the only species that had its maximum near the sewage supply area. The species was also reported from the harbours of Ijmuiden and in the Noordzeekanaal (Wibaut and Moens, 1938).

Braarud and Bursa (1939) in their 1932-33 study described N. delicatissima as an oligosaprobe responding unfavourably to

sewage-contaminated water with its greatest numbers occurring outside the Oslo islands. This disagrees with the distribution in 1938, when in July the maximum population was found in the inner Oslo Harbour, where there were 136,000 cells/l at the surface (Braarud, 1945). This species was also recorded in abundance in the harbours of Ijmuiden (Wibaut and Moens, 1938). N. delicatissima also seemed to flourish in the nutrient-rich waters of St. John's Harbour, although the concentrations were much lower than in Oslo Harbour with only 2,566 cells/l recorded at the surface in June at Station 2.

A comparative analysis of some major diatom species in this study seems to agree with Braarud's (1945) conclusion that, while summer populations of diatoms appeared to flourish in the nutrient-rich water of Oslo Harbour, there were no specific diatom indicators of polluted water.

Distephanus speculum

The occurrence of the silicoflagellate, Distephanus speculum, was definitely a fall phenomenon; it was virtually absent from May to August. The greatest numbers occurred in September in Aquaforte Harbour (860 cells/l at 22m) and in November at Station 2 (266 cells/l at 10m; Table VII). The population at Station 1, St. John's Harbour was extremely small, only 30 cells/l at 10m in September. Similarly, it was not tolerant of the low salinities in the Noordzeekanaal,

although it was reported in large quantities in the harbours of Ijmuiden (Wibaut and Moens, 1938). It was reported by Movchan (1970) as one of the major species located around the Grand Banks. However, it was not an important species in the coastal waters off Labrador (Iselin, 1930).

Ceratia

The temperate oceanic species Ceratium fusus had the largest numbers per liter of the ceratia, and was found in greatest abundance in November at Aquaforte Harbour, when at 10m the count was 237 cells/l (Table VII). It may be inferred that the species responds to the less nutrient-rich water at Aquaforte. This agrees with the finding of Platt et al. (1970) that C. fusus was more prevalent in St. Margaret's Bay than in the polluted waters of Bedford Basin. It was reported as a sub-dominant species in St. Margaret's Bay in all seasons except spring, while it appeared as a sub-dominant species only in the fall at Bedford Basin.

However, many authors associate this species with environments having a high nutrient content. In St. Margaret's Bay, Saifullah (1969) described C. fusus as favouring high temperatures and nutrient-rich water. Wibaut and Moens (1938) described C. fusus as a species which could tolerate the sewage-contaminated waters in the harbours of Ijmuiden. Braarud and

and Bursa (1939) described this species as a mesosaprobe which could take advantage of nutrients from highly-contaminated waters without showing any detrimental effects. Braarud (1945) cautioned against using the ceratia as indicators of polluted water since their largest numbers were located just outside the main sewage supply area. The numbers in Oslo Fjord were much higher than those the present study; in August, 2,100 cells/l were recorded at the surface.

The largest numbers of Ceratium longipes were usually found at Aquaforte Harbour; in November, 155 cells/l were recorded from 10m (Table VII). However, in August, 1970, the species was most abundant at Station 2 with 137 cells/l at 22m. The latter distribution was similar to that of Platt et al. (1970). C. longipes was found in greater concentrations in Bedford Basin than in St. Margaret's Bay; they dominated the phytoplankton from July to December in the Basin.

The oceanic species, Ceratium arcticum, reached its population peak in August when, at Station 2, 159 cells/l were recorded from 10m, and at Aquaforte Harbour there were 209 cells/l from 22m (Table VII). They did not penetrate the central basin (Station 1) of St. John's Harbour to any appreciable extent.

Peridinium depressum

The population of the cosmopolitan species, Peridinium depressum, reached a maximum in May. It was most abundant in St. John's Harbour, especially at Station 1, where 138 cells/l were recorded from 10m (Table VII). At Station 2, the largest count was 60 cells/l from 10m, and at Aquaforte Harbour it was 54 cells/l from 0m.

Similar distributions were reported in two other nutrient-rich waters. P. depressum was present in greater concentrations in the polluted waters of Bedford Basin where it was a sub-dominant species in all months except April and May. At St. Margaret's Bay, it was important only during the summer months (Platt et al., 1970). The three peridinians identified in this study, P. depressum, P. ovatum and P. pellucidum, were also reported in the harbours of Ijmuiden by Wibaut and Moens (1938).

Dinophysis spp.

The neritic species, Dinophysis norvegica, showed an irregular distribution pattern. The largest population was found at Aquaforte Harbour where 80 cells/l from 10m were noted in August: at Station 2, the largest numbers were recorded in June with 29 cells/l from 10m (Table VII). Another species

of the same genus, D. ellipsoides, showed a more erratic distribution. The only collection in which it was abundant was in June, at Station 2, with 96 cells/l at the surface (Table VII). Both Dinophysis spp. were virtually absent at Station 1, St. John's Harbour. Only D. norvegica was recorded as fairly common in the coastal waters off Labrador (Iselin, 1930) and around the Grand Banks (Movchan, 1970).

Unarmoured dinoflagellates

Many of the unarmoured dinoflagellates, Amphidinium sp., Gymnodinium pygmaeum, G. simplex, Gymnodinium spp. "B" and Gyrodinium glaucum were abundant at all three stations throughout the year. However, the quantities at Station 1, St. John's Harbour greatly surpassed those at the other stations. Both the lower salinities and the high nutrient content of the inner harbour waters favoured the extensive growth of this group of dinoflagellates.

f. Euglenophyceae as indicators of trophic levels

The Euglenophyceae have often been associated with eutrophic conditions, both in fresh and estuarine waters. However, as Braarud (1945) pointed out, difficulties arise when using phytoplankton as indicators of polluted or well-fertilized waters. It is imperative that the entire population is considered in terms of seasonal abundance, since seasonal fluctuations of the phytoplankters are not directly connected with changes in the degree of pollution.

Brinley (1942) regarded the presence of large numbers of Euglena sp. as an indication that the Ohio River was heavily polluted. Patrick (1965) in a study of streams, stated that Euglena and Oscillatoria were found to be the two genera most tolerant to pollution by over fifty percent of the investigators reviewed. However, she thought that the prevalence of these two species was typical of polluted (toxic effluents) areas rather than of eutrophic (nutrient increases) areas.

Euglena spp. were one of the more important groups of algae recorded in the Auckland sewage treatment ponds and in the adjacent heavily polluted waters (Haughey, 1969). Pavoni (1963) found that large concentrations of nannoplankton species from the Euchlorophyceae and the Euglenophyta groups were typical of hypertrophic conditions of Swiss lakes (Figure 24).

Conover (1956) listed a Euglena species as a "major" phytoplankter in the inshore waters of Long Island Sound where it occurred sporadically the year round, but flourished during the summer months when it was associated with "red tides". Its highest concentration was 217,000 cells/l. In laboratory experiments, it was found to require high nitrate concentrations for optimum growth.

Braarud and Bursa (1939) described a polysaprobic species, Eutreptia lanowi, from the station nearest the Oslo Harbour. It was recorded in an abundance of 2,030,000 cells/l in 1932-33, and was considered to be an indicator of highly contaminated waters. Braarud (1945) noted that the species was not as numerous in the 1935-39 study, and concluded that, although it is characteristic of polluted waters, it cannot be used alone as an indicator species since its occurrence depends mainly on warm summer conditions. According to Braarud, Steuer, in 1903, had described Eutreptia lanowi in a canal at Trieste.

Lackey (1964) described the Euglenophyceae as a group which is euryhaline, and which especially seems to survive in brackish water. In Great South Bay, the species Eutreptia and Eutreptiella were responsible for blooms near sewer outfalls. It was indeed very surprising that Lackey and Lackey (1970) found that the Euglenophyceae were poorly represented in the polluted St. John's Harbour since they sampled the surface

layer of the harbour at the same time as in the present study. The only variable was that their sample was taken from the shore. Euglena sp. "A", as identified in this study, was the only large, readily detectable species which was found in great abundance (Results; Euglena sp. "A"), and whose concentrations were consistently highest in the central basin (Station 1) of St. John's Harbour (Table VII). As such, it is the only species which may be considered as a reliable indicator of pollution. However, its bloom populations did not persist throughout the year, and therefore the changes with season are not directly connected with changes in the degree of pollution. Thus, the validity of this species as an indicator is limited.

SUMMARY AND CONCLUSIONS

1. Two stations in St. John's Harbour and one station in Aquaforte Harbour were sampled monthly at four depths, 0, 5, 10 and 22m, during the summer and fall of 1969, and the spring and summer of 1970. The collections were analysed for dissolved oxygen, salinity, temperature and phytoplankton content. Secchi disc readings were also taken.

2. Of the 85 species identified, 9 were Chlorophyceae, 1 was an Xanthophyceae, 45 were Bacillariophyceae, 2 were Chrysophyceae, 3 were Euglenophyceae, 23 were Dinophyceae and 2 were Cryptophyceae. There were also four unidentified categories: μ-cells, flagellates, naviculoids and gymnodinians.

3. An analysis of the seasonal variation in volumes of several species indicated that the interspecific variation was great enough to warrant continuous measurement of a species throughout the year, and therefore, a single set of measurements is invalid.

4. The seasonal distribution of the phytoplankton at the two harbours differed. At St. John's Harbour, the Euglenophyceae were responsible for the summer maximum in the population. This peak was much larger than the two dinophycean increases in late fall and spring. At Aquaforte Harbour, the

largest population was the spring diatom bloom. This was followed by a smaller, early summer diatom increase. The Dinophyceae also exhibited two peaks in growth, one in late summer and another in late fall. The presence of various maxima in the phytoplankton population is typical of temperate, coastal environments.

5. Considering the diatoms and the armoured dinoflagellates, the most abundant phytogeographical group were the boreal forms, of which half were neritic and half oceanic, indicating the strong influence of oceanic water from the Labrador Current in an estuarine environment.

6. It was established that St. John's Harbour received large concentrations of nutrients from untreated sewage and manufacturing- and processing plant effluents and was heavily polluted, while Aquaforte Harbour was relatively unpolluted. Evidence for the eutrophic state of St. John's Harbour was supplied from several parameters.

7. Analysis showed that the bottom layers in the central basin (Station 1) of St. John's Harbour were deficient in oxygen especially during the summer months. This stagnation is an important indicator of eutrophication. Supersaturation of these bottom waters in November indicated that an influx of

ocean water had replenished this stagnant layer. At the Narrows (Station 2) and at Aquaforte Harbour, the waters were supersaturated at virtually all depths throughout the sampling period.

8. The use of the Secchi disc as an indicator of pollution is questionable because, although the disc values were consistently lower at Station 1, St. John's Harbour than at the other two stations, the values at the former station were lower in November and February than in the summer months when the phytoplankton productivity was higher.

9. The annual standing crop at Station 1, St. John's Harbour was almost three times that at Aquaforte Harbour; this is directly attributable to the nutrient enrichment from domestic effluents.

10. When classified by size, the phytoplankton consisted of 9 species of ultraplankters plus μ-cells and flagellates "B", 45 species of nannoplankters plus naviculoids, gymnodinians and flagellates "A", and 31 species of net plankters. The ultraplankton was dominant in the early fall at both harbours. The nannoplankton was more abundant than the net plankton at both St. John's Harbour stations, while the two groups were found in about equal abundance at Aquaforte

Harbour. The large populations of nannoplankton at St. John's Harbour are supported by the nutrient-rich sewage effluents.

11. The distribution of the seven algal groups and their major species is discussed in some detail, and comparisons are made with other eutrophic, estuarine environments: the Oslo Fjord in Norway, St. Margaret's Bay and Bedford Basin in Nova Scotia, and the harbours of Ijmuiden and the Noordzeekanaal in the Netherlands.

12. Especially Euglena sp. "A", and also the micro-flagellates were observed in great abundance in the surface waters of the central basin (Station 1) of St. John's Harbour and they may be considered as indicators of pollution, recognizing the limitation of these species as true indicators since their dominance was recorded only during the summer months.

APPENDIX I

Total biomass ($\mu^3.10^6/dm^2$) for each month at the three stations.

MONTH	STATION 1	STATION 2	AQUAFORTE
	ST. JOHN'S HARBOUR		HARBOUR
JULY, 1969	75,961	12,781	17,428
AUGUST	34,945	15,029	14,828
SEPTEMBER	7,957	6,157	8,984
OCTOBER	4,778	-	7,981
NOVEMBER	9,447	6,419	9,528
MAY, 1970	42,434	26,886	27,390
JUNE	23,914	18,651	7,941
JULY	134,310	34,032	15,534
AUGUST	15,903	15,761	18,189

APPENDIX II

Monthly biomass of the major species, expressed as a percentage of their respective algal groups.

Euglena sp "A" - EUGLENOPHYCEAE

MONTH	STATION 1 ST. JOHN'S HARBOUR	STATION 2 ST. JOHN'S HARBOUR	AQUAFORTE HARBOUR
JULY, 1969	100	95	100
AUGUST	100	100	97
SEPTEMBER	61	47	100
OCTOBER	100	-	-
NOVEMBER	4	2	-
MAY, 1970	2	1	-
JUNE	98	92	0
JULY	100	99	56
AUGUST	99	96	41

μ-cells - CHLOROPHYCEAE

JULY, 1969	69	87	82
AUGUST	93	37	78
SEPTEMBER	91	88	83
OCTOBER	99	-	87
NOVEMBER	88	84	87
MAY, 1970	97	99	67
JUNE	99	87	97
JULY	93	94	97
AUGUST	97	96	91

(Cont'd.)

APPENDIX II (Cont'd.)

MONTH	STATION 1 ST. JOHN'S HARBOUR	STATION 2 ST. JOHN'S HARBOUR	AQUAFORTE HARBOUR
Navicula spp. "D" - BACILLARIOPHYCEAE			
JULY, 1969	1	1	4
AUGUST	65	57	1
SEPTEMBER	27	49	19
OCTOBER	66	-	46
NOVEMBER	68	55	42
MAY, 1970	4	5	3
JUNE	67	21	15
JULY	6	53	3
AUGUST	19	53	79
Navicula spp. "B" - BACILLARIOPHYCEAE			
JULY, 1969	7	1	0
AUGUST	11	-	1
SEPTEMBER	7	11	16
OCTOBER	6	-	5
NOVEMBER	4	0	8
MAY, 1970	0	0	1
JUNE	7	5	7
JULY	2	6	2
AUGUST	9	10	9
Chaetoceros spp. - BACILLARIOPHYCEAE			
May, 1970	59	69	82

APPENDIX II (Cont'd.)

MONTH	STATION 1 ST. JOHN'S HARBOUR	STATION 2 ST. JOHN'S HARBOUR	AQUAFORTE HARBOUR
Peridinium depressum - DINOPHYCEAE			
JULY, 1969	0	6	51
AUGUST	2	21	19
SEPTEMBER	9	10	29
OCTOBER	6	-	16
NOVEMBER	9	8	10
MAY, 1970	90	81	80
JUNE	47	57	54
JULY	1	9	49
AUGUST	17	15	18
Ceratium longipes - DINOPHYCEAE			
JULY, 1969	-	8	-
AUGUST	-	10	12
SEPTEMBER	5	39	35
OCTOBER	5	-	4
NOVEMBER	26	37	29
MAY, 1970	1	0	1
JUNE	1	3	2
JULY	0	4	0
AUGUST	2	25	8

APPENDIX II (Cont'd.)

MONTH	STATION 1 ST. JOHN'S HARBOUR	STATION 2 ST. JOHN'S HARBOUR	AQUAFORTE HARBOUR
Ceratium arcticum - DINOPHYCEAE			
JULY, 1969	0	9	6
AUGUST	-	8	16
SEPTEMBER	1	1	1
OCTOBER	-	-	-
NOVEMBER	8	17	5
MAY, 1970	-	0	0
JUNE	4	5	2
JULY	1	7	2
AUGUST	2	41	37
Glenodinium sp. - DINOPHYCEAE			
JULY, 1969	80	17	2
AUGUST	7	52	4
SEPTEMBER	3	1	2
OCTOBER	37	-	3
NOVEMBER	5	3	1
MAY, 1970	0	0	1
JUNE	0	0	8
JULY	0	1	20
AUGUST	4	3	3

APPENDIX II (Cont'd.)

MONTH	STATION 1 ST. JOHN'S HARBOUR	STATION 2 ST. JOHN'S HARBOUR	AQUAFORTE HARBOUR
Gymnodinium spp. "B" - DINOPHYCEAE			
JULY, 1969	6	1	3
AUGUST	81	2	2
SEPTEMBER	7	3	3
OCTOBER	2	-	0
NOVEMBER	6	2	1
MAY, 1970	0	-	0
JUNE	3	0	0
JULY	88	65	1
AUGUST	5	1	8
Gyrodinium spirale - DINOPHYCEAE			
JULY, 1969	2	5	16
AUGUST	0	0	5
SEPTEMBER	4	2	8
OCTOBER	-	-	-
NOVEMBER	2	9	4
MAY, 1970	3	10	12
JUNE	7	7	19
JULY	1	2	17
AUGUST	1	4	7

APPENDIX II (Cont'd.)

MONTH	STATION 1 ST. JOHN'S HARBOUR	STATION 2 ST. JOHN'S HARBOUR	AQUAFORTE HARBOUR
Gymnodinium pygmaeum - DINOPHYCEAE			
JULY, 1969	-	1	3
AUGUST	4	0	1
SEPTEMBER	15	0	2
OCTOBER	1	-	0
NOVEMBER	8	1	1
MAY, 1970	1	0	1
JUNE	18	2	2
JULY	4	1	2
AUGUST	21	1	3

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